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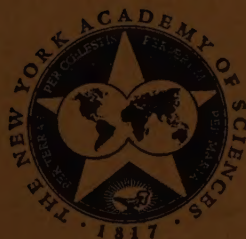
MAN-MADE FIBER PROGRESS

BY

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* This series of papers is the result of a conference on *Man-Made Fiber Progress* held by The New York Academy of Sciences, Section of Physics and Chemistry, on October 12, 1956.

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INTRODUCTION

By Frank C. Collins

Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

On behalf of The New York Academy of Sciences I thank the contributors to this monograph. The publication of this work was originally suggested by Herman Mark of the Polytechnic Institute of Brooklyn, Brooklyn, N. Y., who has contributed so greatly to the development of macromolecular chemistry. The rapid advances in the field of fibers and textiles make this monograph most timely.

Man-made fibers are, perhaps, of even greater interest and importance to the general public than they are to the scientific and industrial communities. Fibers and the fabrics derived from them provide one of the basic requirements for human existence, and their production and distribution constitute one of our very largest industries. Consequently, the work reported in this publication is of immediate and widespread importance.

Indeed, the progress in man-made fibers is a central element in the industrialization of the world and the consequent elevation of living standards everywhere. Fibers and fabrics now can be engineered to meet specific requirements, thus freeing us from the restrictions imposed by the inherent limitations of the natural fibers.

Investigators who work in this area have a satisfaction denied to most other scientists; namely, the fact that the practical value of their labors becomes apparent very quickly. These results are not restricted to the laboratory or to the learned journals, but rapidly become part of the daily life of everyone; personally through the improved serviceability and appearance of clothing and the decorations of the home and, less directly, through the prosperity resulting from the continued expansion of the great textile industry.

If one of the purposes of science is to increase the material well-being of mankind, the scientific investigators who work with man-made fibers truly may be said to be in the vanguard of progress.

INTRODUCTORY REMARKS

By J. J. Press

*Polytechnic Institute of Brooklyn and United States Navy Clothing and Textile Office,
Brooklyn, N. Y.*

Within a relatively short time, the chemical industry has made available an entire range of new and potential fibers with characteristics that can be tailor made to meet a wide variety of consumer needs. Important new developments in this rapidly growing field include industrial materials that are lighter in weight, stronger, and more durable; clothing that resists wrinkling and holds creases even through laundering; stretch socks; high-bulk washable sweaters; furlike coat fabrics; and durable, resilient felts.

Progress is being made on two major fronts. On the one, the properties of fibers are being improved both for specific application and, through such qualities as increased dyeability and better whiteness, for general utility. On the other, with so many unique fibers already available, considerable emphasis is being placed on applications research as a guide to the development of new markets and the expansion of existing ones. It is the purpose of this monograph to review and to help integrate the recent advances in the development of new and better fibers with our growing understanding of how best to use them.

In the first section of this monograph, which concerns new fibers, leading experts from major producers review advances in the development and production of cellulosic, polyamide, polyester, acrylic, and other vinyl fibers.

In the second section, representatives from academic, industrial, and consumer organizations discuss the comparative evaluation of fiber characteristics, advances in dyeing and finishing, new developments in stretch and bulk yarns, and the educational needs of the consumer.

The textile industry makes products of direct interest to every man, woman, and child. Despite this, few people appreciate the magnitude and rate of the changes now taking place in textiles and their growing contribution to an easier and better way of life. This revolution is motivated to a considerable extent by new and improved fibers and, of equal importance, by a rapidly growing understanding of their proper uses. It is the purpose of this monograph to provide an opportunity for a broad review and an assessment of some of the more important developments in this rapidly changing field.

This introduction would be incomplete if it did not gratefully acknowledge the special credit due to Herman Mark for inspiring the conference and to John H. Dillon for his very able and realistic chairmanship of the session on application.

RECENT PROGRESS IN CELLULOSE AND CELLULOSE ACETATE FIBERS

By J. A. Howsmon

American Viscose Corporation, Marcus Hook, Pa.

As the first man-made fiber to attain general acceptance, viscose rayon and the research and development based upon it have served as a focal point for a major part of our present fiber technology. Although the use of fibers is essentially as old as man himself, the basic knowledge needed for the development of synthetic fibers was not obtained until the early 20th century when the study of the structure of cellulose fibers gained momentum. For many years after its introduction, viscose rayon was, indeed, merely a poor artificial silk. Its chief attraction was its relatively low cost, but the development work inspired by this weak, unstable fiber led to a better understanding of fiber-handling processes that previously had been passed unchanged from one generation to the next. In a technical sense, the role played by viscose rayon in accelerating the acquisition of basic knowledge of fiber technology may well be its most important contribution to science. However, regenerated cellulose fibers themselves have benefited from this improved technology, and continued improvements in the fiber have extended its use so that today it is accepted as a commodity in its own right.

In recent years, significant advances in the regenerated cellulose and cellulose acetate fiber industry have been made in process modifications resulting in improved physical properties; in product development of cellulose fibers designed for specific end use; in processes for improving the appearance, texture, covering power, and dimensional stability of fabrics; and in variation of fiber properties and usage by chemical modification of the basic polymer. Rather than attempt to summarize all this work, the remainder of this discussion will consist primarily of brief case histories of three current developments. These are: the development of "super" rayons; the creation of products made from crimped rayons; and the exploitation of cellulose triacetate.

Within the past thirty years, the regenerated cellulose fiber industry has made three major technological advances. The first of these, stretch spinning, raised viscose rayon from its lowly status as an artificial silk and gave it its own place in the apparel field. The major improvements resulting from controlled stretch during spinning were increased strength and an improved dimensional stability of the fiber. The second, a modification in chemical process, resulted in still stronger, tougher fibers and extended regenerated cellulose fibers into industrial uses, primarily as tire cord. The third, best described as a refined combination of the first two, is still in its infancy, and its full impact on the rayon industry has not yet been realized.

This development is the best current example of process modification.

In brief review, the regenerated cellulose fiber process follows these steps:

(1) reaction of alkali cellulose with carbon bisulfide to form a cellulose

xanthate; (2) solution of this xanthate in aqueous sodium hydroxide (5 to 8 per cent); (3) precipitation of the cellulose xanthate by the action of a bath containing sulfuric acid, a heavy metal salt (usually ZnSO_4), and an alkali metal salt (usually Na_2SO_4); and (4) controlled stretching of the still swollen fiber to yield the desired physical properties.

In its simplest form, the spinning of rayon is a precipitation that is controlled to yield a solid that has the form and properties of a fiber in the usual sense, and the rules governing the precipitation of molecules should apply. However, even true molecular dispersions of cellulose xanthate must be considered as colloidal systems because of the large molecular size and area per unit volume. The precipitation of the fiber from viscose solutions by extrusion into a coagulating bath involves at least three major factors: (1) decomposition of cellulose xanthate to cellulose by the action of acid or heat; (2) the formation of insoluble heavy metal cellulose xanthates; and (3) the removal of solvent by the action of concentrated spinning baths (salting out).

By controlling the relative rates of these and other variables in the process, it is possible to produce wide variations in the properties of the precipitated fibers. For example, precipitation controlled primarily by rapid decomposition of cellulose xanthate or by rapid salting out yields round fibers (FIGURE 1a) with relatively low tenacity and elongation. Precipitation controlled by insoluble salt formation or other interactions that delay xanthate decomposition and inhibit crystallization yields serrated fibers marked by the presence of a tough "skin" layer around the periphery of the fiber (FIGURE 1b). These fibers generally have both higher tenacity and higher elongation than fibers that do not exhibit a skin effect. The difference in physical properties of these two types of fiber is illustrated in TABLE 1. The thickness of the skin layer can be varied and is evaluated experimentally by the fact that the outer or skin layer retains certain dyes, while these same dyes can readily be washed from the core of the fiber. According to Morehead and Sisson,¹ the skin layer is formed under conditions that favor good molecular orientation and low crystallization. In any event, the entry of

TABLE 1
PHYSICAL PROPERTIES OF TEXTILE RAYONS

Fiber description	Dry tenacity (gm./den.)	Dry elongation (per cent)	Wet tenacity	Wet elongation
Round, no skin				
Low stretch.....	1.61	17.3	0.70	21.3
High stretch.....	2.0	8.0	1.35	12.0
Serrated, skin-core				
Low stretch.....	2.4	28.2	1.4	45.5
High stretch.....	3.1	18.4	2.04	23.3

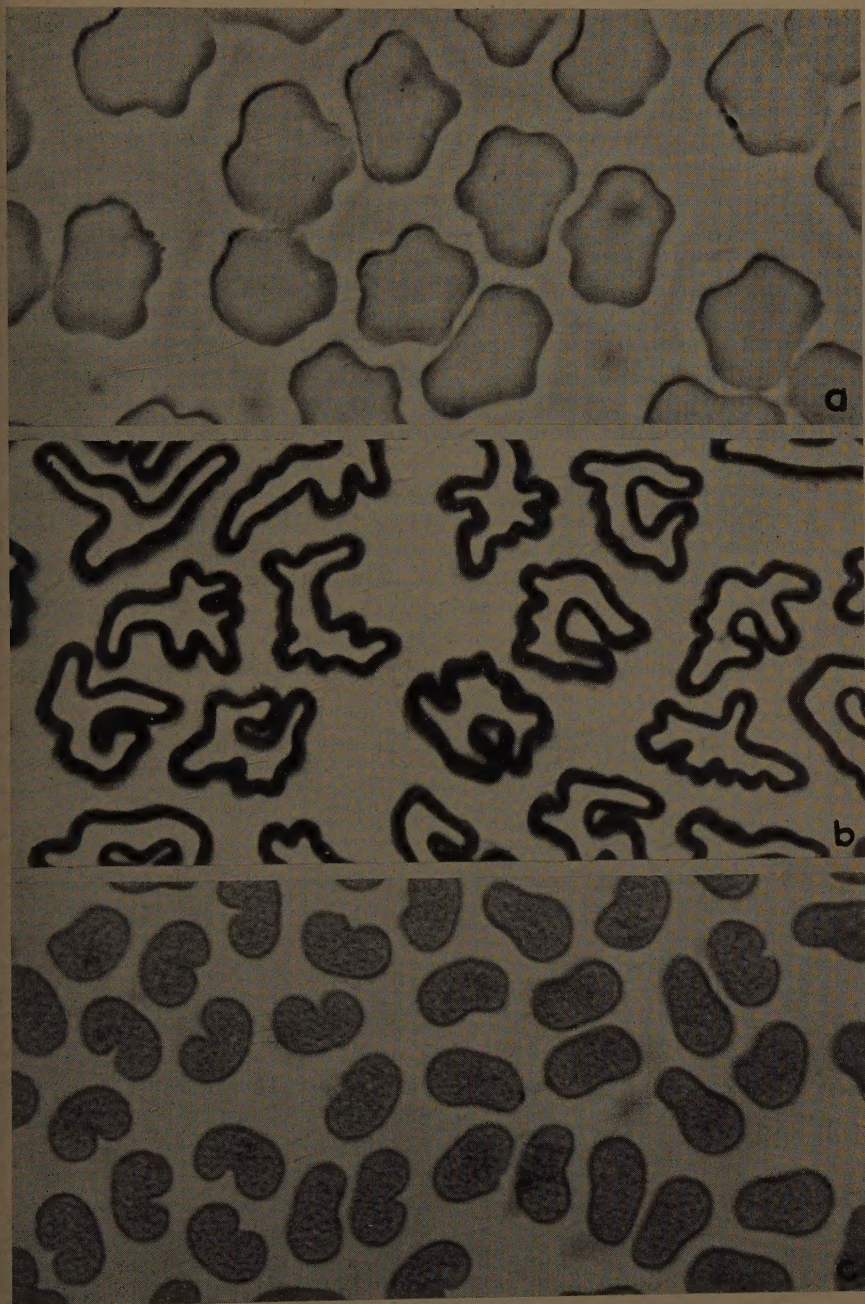


FIGURE 1. Cross-section photographs of three types of rayon fibers: (a) early rayon with all-core structure; (b) rayon with skin-core structure; and (c) super rayon with all-skin structure.

regenerated cellulose fibers into industrial fields was made possible by the production of these strong, tough fibers.

The development of the "super" rayons within the last few years is a natural extension of the above processes. These new fibers are marked by a very thick skin or, in some cases, by an "all-skin" structure (FIGURE 1c) and a relatively smooth cross section. They are produced by processes similar to those used in the production of the original high-tenacity rayons. The production of these yarns has been made possible by maintaining the several process variables that favor skin formation at optimum levels and by the use of certain chemical additives that allow wider control of the relative rates of xanthate regeneration, zinc cellulose xanthate formation, and salting out of the polymer. The super rayons are marked by exceptionally high tenacity, high elongation, high fatigue life, and low swelling. A comparison of the tensile properties of these fibers and of tire cords made from them with similar yarns having a skin core structure is given in TABLES 2 and 3.

At the present time, yarns of this type have been used extensively only in tire cord, and then primarily because of the improvement in strength. However, this type of rayon is well suited for, and is finding use in, such diverse places as conveyer belts, V-belts, industrial sewing thread, abrasive cutoff wheels, polishing wheels, sanding discs, safety belts, paper reinforcement, and tapes. The so-called super rayons have been on the market only a short time, and additional steady improvement in their properties can be

TABLE 2
TENSILE PROPERTIES OF HIGH-TENACITY RAYON YARN

	1944	1949	1956
Dry tenacity (gm./den.).....	3.5	4.0	5.3
Dry elongation, per cent.....	9.9	10.0	11.0
Wet tenacity (gm./den.).....	2.3	2.5	4.2
Wet elongation, per cent.....	19.0	21.0	30.0

TABLE 3
TENSILE PROPERTIES OF RAYON CORD

	1944	1949	1956
Cords (12 × 12 twist)			
Conditioned strength, lb.....	19.0	21.4	31.7
Elongation, per cent.....	13.0	15.4	19.2
Oven dry strength, lb.....	23.5	25.2	35.0
Elongation, per cent.....	10.0	12.0	16.6

expected within the next few years. Most research on the applications of these fibers has been carried out in industrial uses, and their big potential seems to be in these fields. However, the combination of high strength and low swelling also offers possible fabric properties heretofore attainable only by resin treatments. Therefore these super yarns may have wide application in apparel as the processes for manufacture are improved.

At the merchandising level, there is a strong contrast between the practices of the cotton and woolen industries and the regenerated cellulose industry. For the most part, cotton and woolen fabrics are made to rigid specifications that more or less ensure the quality of the product. The specifications have been held consistent over long periods of time. Although rayon and acetate fibers have become market commodities in the same sense as cotton, the end-product specifications for their use show extreme variation over short periods of time. As a general rule, a low-priced fiber in cheap construction does not produce a better fabric. This constant trading-down of fibers and fabrics to meet a price, combined with the use of regenerated cellulose fibers as substitutes for silk, wool, and cotton, whether or not the end use is fitted to the fiber, has resulted in wide misuse of rayon and acetate fibers. At one time, the viscose industry attempted to combat this tendency by modifying the fibers to make them resemble cotton, silk, or wool and, in so doing, they became accessories after the fact.

The trend today is a little more realistic; for the most part, fibers are modified to obtain properties needed in specific end uses in which the fiber can stand on its own merit in preference to being produced merely as a poor substitute for cotton or wool. For example, there is a large potential market for white, level-dyeing crimped fibers that can readily be converted into crimped-pile fabrics that have eye appeal and utility in upholstery, clothing, bedspreads, and carpeting. Although these fields generally utilize staple fiber, a continuous-filament fiber in which crimp could be developed when desired offers a cost advantage to the converter.

The development of such a fiber as a continuous filament or staple required little if any new process development and demonstrates the advantages which can be obtained by combining several known processes. Methods for manufacturing crimped rayon have been known for about fifteen years, and it is now generally agreed that any rayon that has an unbalanced structure will crimp.² This imbalance is most analogous to that of the bimetallic strip used in thermostats. In rayon fibers, crimping occurs if one side of the fiber has better elasticity or a greater tendency to shrink or swell than the other. The first crimped rayon fibers were produced by extruding two different viscose solutions through each orifice in the spinneret. The two viscose solutions were chosen so that, after coagulation and stretching, that portion of the fiber produced from one viscose solution had a shrinkage greater than that of the other. When allowed to shrink, these fibers formed a regular crimp, with the side of the fiber exhibiting the highest shrinkage always lying on the inside of the coil. Later work showed that crimpable fibers could be produced from a single viscose solution by adjusting spinning conditions so that the skin-core structure was unbalanced, either by broken

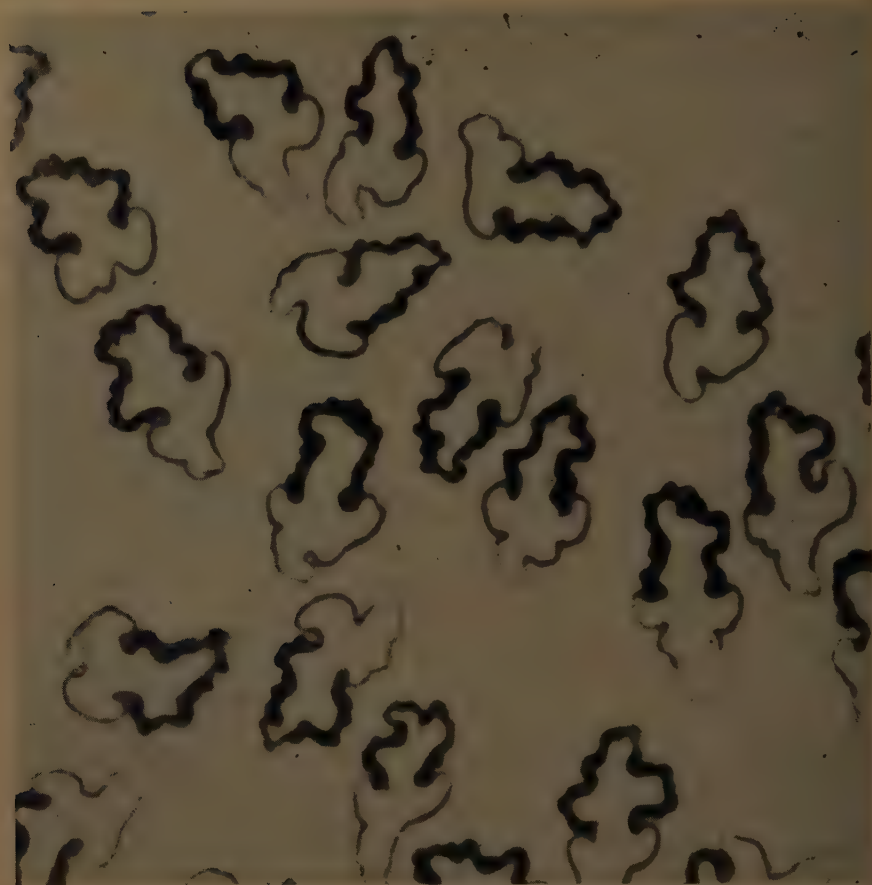


FIGURE 2. Cross-section photograph of crimpable rayon fibers.

skin structure as illustrated in FIGURE 2 or by a skin-core structure in which the skin is thicker on one side of the filament than on the other. If such unbalanced fibers are not allowed to shrink during manufacture they can be collected as a straight, continuous filament and thus serve as a potentially crimpable fiber. The treatment of these fibers with any swelling medium that induces differential shrinkage in the two portions of the fiber will produce crimp at any later time. The two most important swelling media for this use are aqueous sodium hydroxide and water. The crimpability of fibers of this type is illustrated in TABLE 4, which also illustrates that fibers that will crimp in a caustic solution, but not in water, or fibers that will crimp in water alone can be produced. The crimp in these yarns can be developed readily by water prior to dyeing or even during the dyeing operation.

The measurement of crimp rating (percentage of shrinkage) and the number of crimps per inch (TABLE 5) is a simple and rapid means of forecasting the properties of the finished product. For example, fibers with a

crimp rating below 55 per cent produce a shaggy, uneven carpet, while fibers with a crimp rating above 55 per cent usually produce an attractive pile carpet. Generally, a fiber with a crimp rating of 65 per cent with 4 to 6 crimps per inch makes the most attractive carpets. Similarly, a fiber with 15 crimps per inch results in a very flat, tight pile in a carpet. This is normally unattractive as a carpet, except in special cases such as automobile carpets, but is readily adaptable for use in bedspreads.

Solid colors such as those frequently used in carpets may be produced by solution dyeing. In these cases the carpets are essentially loom finished, for the crimp can be developed by a simple water spray.

The use of rayon fibers as an adsorbent is a similar example of end-use development. For use as an adsorbent, a fiber array must be white, have high water adsorbency and good stiffness when wet, must be able to withstand sterilization, and must not slough when rubbed over a surface. Normal rayon staple has none of these properties. The desired whiteness can be achieved by proper bleaching during spinning. The use of crimped fibers results in increased water adsorbency by preventing the close packing of fibers and by increasing the capillary spaces that can hold water. The wet-stiffness necessary can be obtained by increasing the size of the filament beyond normal textile levels. The ability to withstand sterilization at 250° F. requires only a stable finish. Sloughing is prevented by increasing the staple length so that individual fibers will not be pulled out of the mat when it is rubbed against a surface.

The use of these fibers as adsorbent staple offers definite advantages. Rayon fibers offer simplicity in handling in that they are pure as produced and do not require excessive cleaning before fabrication. In fact, they offer

TABLE 4
CRIMP RATING OF LATENT-CRIMP YARNS

Sample	H ₂ O	0.5% NaOH	1.0% NaOH	2.0% NaOH	4.0% NaOH
A	0	6	11	35	55
B	6	21	35	72	77
C	70	73	74	79	81

TABLE 5
CRIMP PROPERTIES OF VISCOSE RAYON YARNS

Denier/filament	Crimp rating (%)	Crimps/inch
18	58.7	4.6
15	57.4	4.9
9	66.5	8.0
2.75	66.1	16.5

cleanliness beyond that obtainable with cotton after any degree of scouring. The resistance to sloughing is excellent and, as a result, rayon adsorbent is superior in many applications, such as photographic processing, where lint is objectionable.

In the past few years, many attempts have been made to expand the use of cellulose acetate fibers by the development of specific products suited to their use. Development has centered about the use of bulked fibers and solution-dyed fibers; neither of these improvements is restricted to acetate alone, but is generally applicable to all man-made fibers. The most important development directly concerning cellulose acetate has been the exploitation of cellulose triacetate fibers, primarily by the Celanese Corporation of America, New York, N. Y.

Cellulose triacetate actually antedates the technological and commercial development of secondary or partially de-esterified cellulose acetate. The availability of cheap solvents for secondary acetate is responsible for the fact that the latter became the second important member of the man-made fiber family. The plastics industry first utilized cellulose triacetate as a film because of its low sensitivity to moisture, its stability, its toughness, its hardness, and its high electrical resistance.

In many respects, cellulose triacetate represents a compromise between cellulose acetate rayon and such fibers as Dacron and nylon. It is quite similar to cellulose acetate in tensile strength, elongation, and abrasion resistance. It has a higher melting point than acetate, Dacron, or nylon, a higher ironing temperature, and good resistance to glazing on ironing, and it can be heat-set by procedures similar to those used on Dacron and nylon. Excellent reviews of fiber properties³ and the dyeing and finishing of cellulose triacetate fibers and fabrics⁴ have been published.

Although the commercial development of cellulose triacetate as a fiber is still in its infancy, it seems that a place must be made for it in the growing list of fibers available for textile use. It seems destined to compete with cellulose acetate in some end uses, and it is capable of extending the use of acetate fibers into new fields in which its improved washability, wrinkle resistance, crease retention, and soil resistance offer advantages over conventional cellulose acetate. Its full potential will probably not be realized for several years.

Man-made cellulose and cellulose acetate fibers have become a permanent part of our economy, and it is doubtful that any new "miracle" fiber will displace them in the near future. The present trends indicate that the newer synthetic fibers will continue to replace regenerated cellulose fibers in some areas, but that these same synthetics will extend the use of regenerated fibers into new fields. The properties of cellulosic and synthetic fibers complement each other to such an extent that the most satisfactory product for many end uses is a fiber blend to which each component contributes specific properties. A major portion of future development work in the fiber industry will be directed toward the evolution of fiber blends that embody particular properties for specific end uses. In addition, the intelligent use of regenerated cellulose fibers alone in end uses specifically

suited to their properties will increase their utility in present uses and allow expansion into new fields. It can also be predicted that continued research and development at the producer level will result in additional improvement in the properties of various fibers and in a variety of tailor-made fibers that should have expanded utility, both singly and as components in fiber blends.

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RECENT PROGRESS IN POLYAMIDE AND POLYESTER FIBERS

By G. M. Richardson, H. E. Stanley, and W. W. Heckert
*Textile Fibers Department, E. I. du Pont de Nemours & Company, Inc.,
Wilmington, Del.*

The principal commercial polyamide and polyester fibers are made from 3 polymers; 66 nylon from polyhexamethylene adipamide, 6 nylon from polycaproatamide, and the polyester fibers from polyethylene terephthalate. These polymers stem from the classical researches of Wallace Carothers and his associates;^{1, 2, 3} the nylons were synthesized and evaluated in the original survey that led to the commercialization of 66 nylon by du Pont in 1939. Polyethylene terephthalate was first synthesized by Whinfield and Dickson.^{4, 5, 6} Dacron polyester fiber, also manufactured by du Pont, and Terylene polyester fiber, manufactured by Imperial Chemical Industries, Ltd., London, England, are based on this polymer.

These discoveries were made during the 1930s and 1940s. At the risk of some oversimplification, it can be said that the researches of this period were concerned mainly with (1) exploratory researches aimed at discovering what kinds of fibers could be made, (2) developmental studies aimed at economical manufacturing processes, and (3) end-use studies that resulted in a limited number of large-volume applications. Numerous basic studies had as their objectives the explanation of experimental observations and the establishment of the basis for new discoveries.

During the early 1950s the production of polyamide and polyester fibers reached a considerable volume. A need for wider markets replaced the demand for expanded production. In short, these industries became of age. This called for a major shift in the research program. It became necessary to accelerate studies of ultimate uses in order to broaden markets and to adapt the fibers for new purposes.

Since most of the recent progress with these fibers has come within the domain of applications research, this discussion will be limited to advances made in this area. Furthermore, I shall treat the subject in an illustrative rather than in an exhaustive manner, since I assume that the readers of this monograph are more interested in current trends and tendencies in this field than in a comprehensive list of recent accomplishments.

The nylons and polyester fibers of today were born with sturdy muscles. They excelled in strength, toughness, resistance to abrasion, elasticity, crease resistance, and what later came to be called "ease-of-care" properties.

These last qualities are called functional properties in our business. Initially, at least, the new fibers failed to excel in esthetic properties. The fabrics made from them were often deficient in such characteristics as hand, or feel, in drape, in texture, and in coloration. This proved to be a great handicap, for in many uses it is precisely these properties of textiles that control the volume of sales. Consequently, the objective of countless investigations has been to improve the esthetic qualities of fabrics made

from these fibers. These are rather unusual problems to assign to chemists and engineers, yet many conspicuous advances have been made by such workers.

Let us begin by considering some of the procedures that have been evolved for improving the texture, elasticity, bulk, and covering power of fabrics made from continuous-filament yarns. Since this subject is covered in detail elsewhere in these pages by Martin H. Gurley, we shall touch upon it only briefly in order to show its relationship to other researches aimed at improving the esthetic features of fabrics made from nylon and polyester fibers.

The synthetic fiber industry originated with the development of continuous-filament yarns—artificial silk, as it is sometimes called. Such yarns are used extensively in women's hosiery where their lack of bulk and covering power is considered a virtue. They are also used in lingerie and in fabrics for clothing of the dress types, such as sheers, failles, and taffetas. For many years continuous-filament yarns were the mainstay of the business. However, in many areas they are now under competitive pressure from the staple fibers, both natural and synthetic, since there has been a strong trend to casual wear in recent years. In garments of this type, the texture, the fuzzy, uneven, dull surface, and the bulk and covering power of staple-fiber fabrics are preferred to the more lustrous, silky appearance and feel of fabrics made of continuous-filament yarns.

Of course, one solution of this problem is to chop the filament yarn into staple fiber and then to spin it back into yarn but, to the scientist, this expedient is an admission of defeat. Attempts to find a better method have given rise to a whole group of textured yarns that are known in this country by their trade-marks: Agilon,* Ban-Lon,* Burmilized,* Flufflon,* Helanca,* Tycora,* and Taslan.*

In all of these products the change in texture and the increase in bulk and cover are caused by permanent crimp, curl, or loops formed in the filaments. This change is illustrated in FIGURE 1.

Let us consider how these processes actually affect filaments. The first 5 of these processes comprise 2 steps, in the first of which a crimp or curl is imparted to the filaments, followed by the second step in which this crimp or curl is set permanently in the fiber by means of heat. All of these processes produce yarns that have a high degree of elasticity compared with yarns spun of untreated filaments. In the case of Helanca yarns, high twist is employed to curl the filaments. The twist is later removed after setting by heat. Ban-Lon yarns are crimped by continuously stuffing them into an enclosure and then allowing them to escape. In all cases the crimp or curl is set into the filament by a heat treatment. This step induces further

* Registered trademarks respectively used to designate textured yarns made in accordance with quality standards set by Deering Milliken & Co., Inc., New York, N. Y.; Joseph T. Bancroft & Sons, Inc., Wilmington, Del.; Burlington Hosiery Co., New York, N. Y.; Marionette Mills, Inc., Coatesville, Pa.; Heberlein Patent Corp., New York, N. Y.; Textured Yarns Co., Philadelphia, Pa.; and E. I. du Pont de Nemours & Company, Inc., Wilmington, Del.

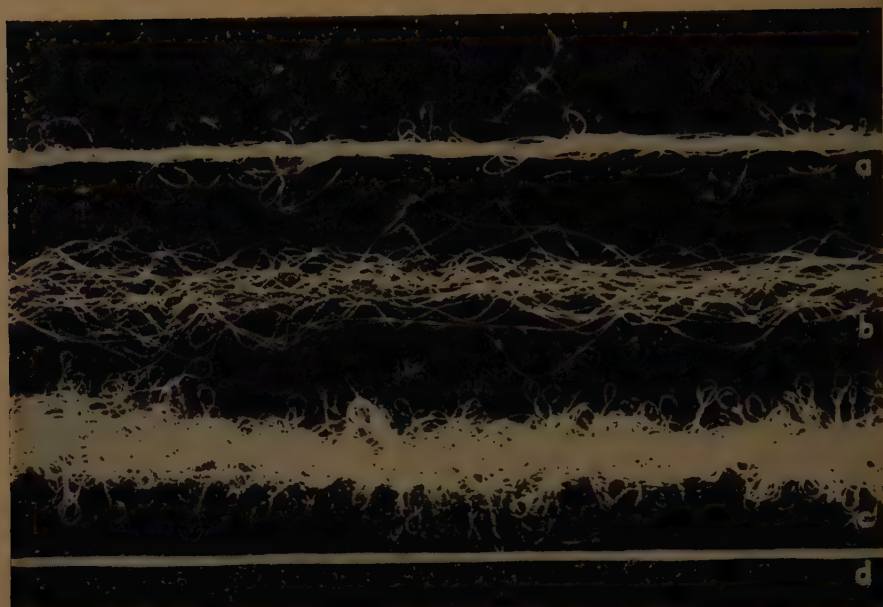


FIGURE 1. Three varieties of textured yarn: (a) Taslan; (b) Ban-Lon; and (c) Helanca. At the bottom (d) is an untextured filament.

perfection of the crystalline areas in the fiber, thus forming new bonds between the molecules making up the fiber; these bonds fix the crimp. Some fibers are incapable of taking a permanent set and do not respond to these processes.

When Helanca nylon yarns were first made it was observed that, if they were stretched out to their full length, the forces tending to restore the filaments to their crimped or curled form were of sufficient magnitude to endow the yarns with very remarkable elasticity. This property of nylon provided the first stretch hose. In this manner an apparently secondary property became of greater importance than that originally sought.

Ban-Lon yarns show intermediate elasticity and a substantial increase in cover. They are finding use in many types of knitwear, such as sweaters.

Taslan textured yarns, invented by A. L. Breen of our Pioneering Research Laboratory, do not rely upon a setting step to fix the bulk or texture. They are made up of single-filament loops randomly spaced and interlocked by frictional forces. They show no more elasticity than do untextured yarns. To make them, continuous-filament yarn is fed through an air jet at a rate faster than that at which it is drawn off by take-up rolls located on the far side of the jet. Although the resulting yarns are only 10 to 20 per cent shorter after texturing, their increase in volume normally amounts to 50 to 200 per cent. The covering power of fabrics so treated may be increased 75 to 100 per cent over that of control fabrics. Fabrics of Taslan have a dry and rather crisp hand. Their frictional coefficients are often three

times greater than those of control fabrics. This may prove to be one of the most useful properties of Taslan textured yarns.

A most promising new product is a shirt made from Taslan. It has been introduced to the trade by the Matson Shirt Company, New York, N. Y., and is made from a Burlington fabric of Taslan-textured Dacron yarn. It has good appearance, a pleasing hand, is comfortable, and soils much less quickly than an ordinary filament shirt because it makes much less contact with the skin. In addition, it has good washing and wearing properties.

Fabric Finishing

Thus far we have considered a variety of procedures for changing the properties of fabrics by treatments applied to their constituent yarns. These are recent innovations. A more orthodox way to improve the esthetic qualities of fabrics is to apply physical or chemical treatments to the fabric itself. This is known as fabric finishing.

In the case of natural fibers and rayon, fabric finishing usually begins with a boil-off or scour in soap and water. Recent studies on the finishing of fabrics constructed of synthetic fibers have not only produced some very attractive fabrics, but are shedding new light on the importance of this first step. It now appears that the swelling and movement of the yarns in a cotton or rayon fabric during the scouring step causes them to shift their position so as to achieve a much more uniform distribution of the yarns in the fabric than ordinarily results from the weaving process alone. This factor minimizes what would otherwise appear as "reediness" or streaks in the fabric. Such streaks have the superficial appearance of dyeing non-uniformities, but they are actually caused by the irregular configuration of the yarns rather than by variations in dye content. However, when fabrics of polyamide or polyester fibers are scoured in soap and water, no analogous swelling takes place, and one might therefore expect that it would often be difficult to avoid reediness or the appearance of dye streaks. This is actually the case.

A recent invention not only lends plausibility to this analysis, but also goes a long way toward solving the problem. It achieves what appears to be a more uniform dyeing of nylon fabrics by carrying out the process in the presence of a phenolic swelling agent under relaxed conditions. Some of the most uniform dyed-nylon fabrics that we have ever seen were prepared in this manner. F. Schulze of our Textile Research Laboratory has obtained evidence, soon to be published, that swelling of the nylon yarns in this manner causes them to redistribute themselves more uniformly in the fabric. Benefits analogous to those accomplished with a relaxed scour of cotton or rayon fabrics are thus accomplished with nylon. This invention, which was purchased by du Pont, is the subject of a pending patent application, and the process has been made available to all dyers of nylon fabrics.

Many cellulosic fabrics are finished subsequent to dyeing by impregnating them with urea-formaldehyde or other analogous resin-forming ingredients that are capable of reacting with the cellulose. After drying, the fabric is heated for a short period during which the resin polymerizes and reacts

with the cellulose to form cross links between the cellulose molecules. These cross links stabilize the fabric in whatever form it existed during the polymerizing step. Surface effects such as embossed impressions are fixed for the life of the cross links. The fabric shows improved resistance to creasing and is more substantial to the touch.

The unique thing about polyamide and polyester fibers is that they depend on heat alone to give them a permanent set, much as do cellulosic fibers impregnated with a methylol urea. They become dimensionally stable; that is, they seek always to return to the dimensions and form in which they are held during the heat-setting step. Embossed patterns are fixed permanently. Properly constructed fabrics improve in liveliness and crease resistance, and they do not lose appreciably in strength or resistance to abrasion. This property gives polyamide and polyester fabrics a versatility that remains only partly exploited to this day.

Heat setting was first used in the preboarding step in the manufacture of nylon hose to fix the stockings in a nonwrinkled state so that they could be dyed without inserting permanent wrinkles. Later a preboarding step was used to shape seamless hose to the desired dimensions. This capacity of nylon for being shaped during preboarding made possible the rise of the seamless hosiery industry to its present position of importance. The dimensional stability imparted to nylon tricot by a heat-setting step is responsible for its manifold uses. Setting with dry heat a little below the melting point has long been known greatly to improve the hand and the wrinkle resistance of fabrics woven of nylon. However, only recently has any use been made of heat setting to modify what might be called the fine-grained structure of nylon fabrics. For example, it is possible to calender nylon tricot fabrics under conditions of high temperature and pressure to achieve a marked change in the feel of the fabric, an increase in its covering power, and a reduction in its thickness. This is illustrated in TABLE 1.

Note in particular that the light transmission of the calendered tricot fabric has been reduced to 2.6 per cent. This compares with 6.7 per cent for the uncalendered tricot and 2.5 per cent for a cotton slip fabric that was deemed to have good covering power. If the fabric is properly heat set, these changes are permanently resistant to washing. In this manner it is possible to prepare a whole series of fabrics varying widely in appearance and in hand from each polyamide or polyester fabric. It would appear that there must be many unexploited opportunities in this field.

TABLE 1
THE CALENDERING OF NYLON TRICOT

	Uncalendered	Calendered
Weight of fabric.....	2.70 oz. per sq. yd.	3.29 oz. per sq. yd.
Thickness (mils).....	0.0120	0.0105
Covering power (light transmission).....	6.7%	2.6%

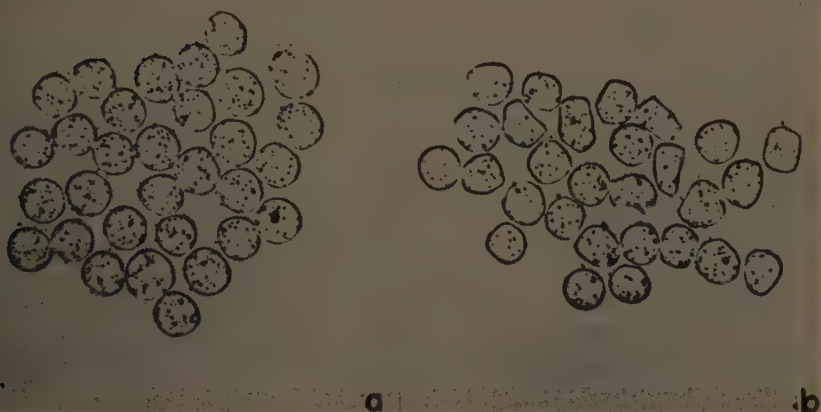


FIGURE 2. Deformation of Dacron polyester fibers by calendering. At the left (a) is shown the cross section of the control fiber; at the right (b) is the cross section of a calendered fiber, reminiscent of that of silk. Both samples are 70-denier, 34-filament yarns of round cross section.

Dacron polyester fiber possesses another very unusual property that offers further versatility in finishing. When the fiber is exposed to strongly alkaline media, surface polymer saponifies and dissolves, but the fiber that remains retains most of its strength unimpaired! When a tightly constructed woven fabric of Dacron polyester fiber is subjected to boiling in 3 per cent sodium hydroxide for about 90 minutes, the weight loss may amount to about 15 per cent, and the fabric then feels much softer, livelier, and generally more attractive. To a certain extent, this improvement in the esthetic qualities of fabrics is analogous to the change that occurs when silk fabrics are degummed, thereby losing approximately 25 per cent of their weight and becoming more open in construction.

Studies by Navin Gajjar of our Textile Research Laboratory have shown that a combination of calendering, heat setting under relaxed conditions, and treatment with caustics imparts a particularly attractive hand to some fabrics of Dacron polyester fiber.

This is what we think happens in each step:

(1) In calendering there is actual deformation of fiber cross sections to make them more like silk. After calendering, the fabric resembles parchment.

(2) During relaxed heat setting, the fabric shrinks and the amplitude of weave crimp is increased and set permanently.

(3) The caustic treatment serves two purposes. First, it hydrolyzes away the outer layers of the fibers. This creates enough free space to permit the weave crimp to act as a multitude of springs. Hence the fabric becomes livelier. Second, the caustic hydrolysis of the calendered yarns actually accentuates the deformation of cross section produced in calendering and produces final cross sections reminiscent of those of silk (FIGURE 3).

The caustic finishing of polyethylene terephthalate fabrics was first disclosed by John D. H. Hall in United States Patent No. 2,590,402. In so far as the process I have described is dominated by this patent, it is available to the public through an agreement between du Pont and Imperial Chemical Industries, which own the patent.

Rugs

Let us now consider an end use for nylon in which recent esthetic advances are paving the way for a success that could not be won with functional properties alone, namely, the 100 per cent nylon rug. Such rugs have been in existence for at least nine years. For a long time their durability has been known to be phenomenal. Witness the department store in Nashville, Tenn. which, as a stunt, placed a 100 per cent nylon rug on one of the principal highways to test its durability. Truck drivers passing over the rug soon entered into the spirit of the test and applied their brakes as they crossed the rug. After it had been crossed by 22,000 automobiles, trucks, and buses the rug was cleaned and examined by store officials, who decided it looked substantially as good as new and quite salable. However, nylon rugs have not sold in the volume that might have been anticipated. Covering power needed improvement both as a way of achieving superior esthetic qualities, and as a route to lower costs. Rugs with uncut pile often "pilled" objectionably during service; that is, they accumulated balls of fiber on the surface of the rugs. There have been difficulties in styling a full line of nylon rugs. All of these are typical esthetic problems, but they are nearing solution.

Initial studies disclosed that the covering power of nylon rug yarns

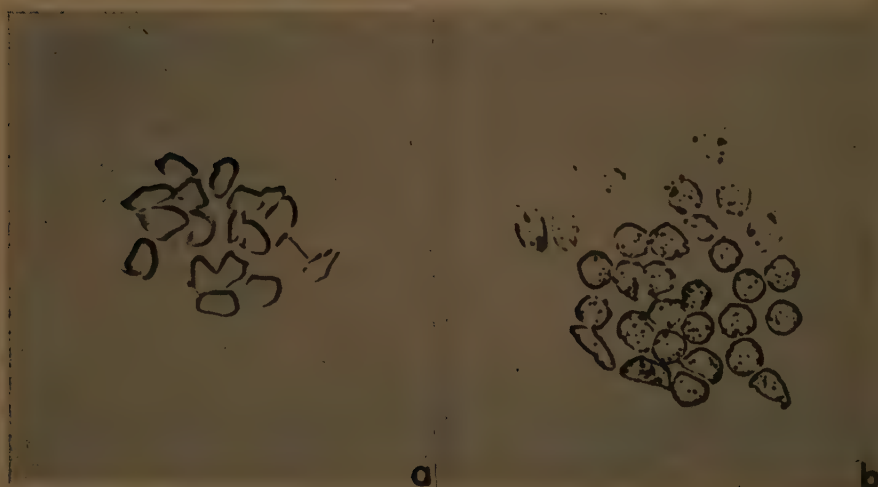


FIGURE 3. Comparison of the cross section of a silk fiber (a) with that of a calendered, heat-set, caustic-treated Dacron fiber (b). Both samples are 70-denier, 34-filament yarns of round cross section.

NYLON CARPETS

VELVET TWIST

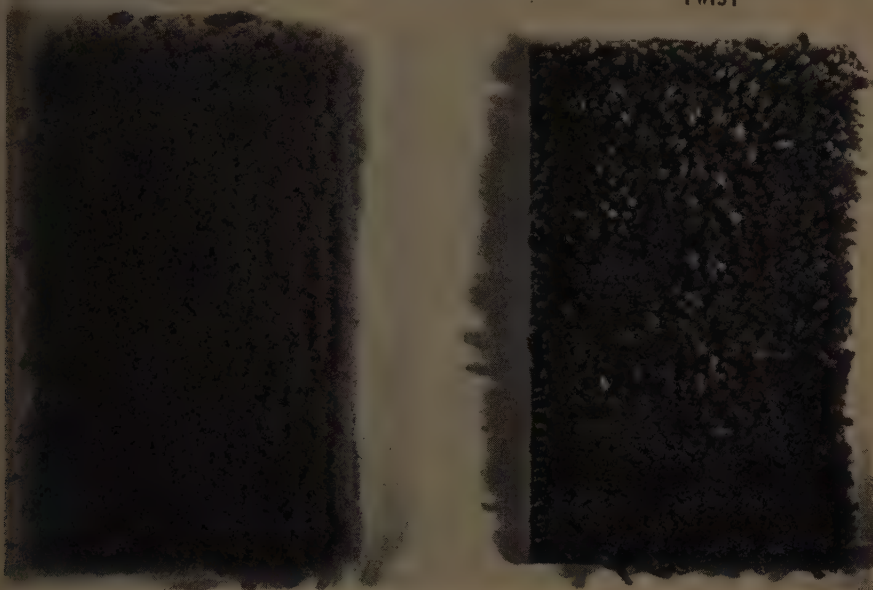


FIGURE 4

increased as the denier* of the filaments was decreased but, unfortunately, resistance to matting, a most important property, fell off with decrease in filament denier. Clearly, a compromise was necessary. A denier of 15 was chosen as optimum for round filaments. Since that time we have varied the shape of the cross section of the fiber, and it has been discovered that filaments with an irregular cross section have up to 25 per cent more covering power than round filaments of the same denier. Normal crush resistance and durability are retained. Staple of this type is now being offered in experimental quantities.

In the meantime, a major improvement in the esthetic qualities of nubby and frieze rugs was made possible by twist-setting studies conducted by du Pont technical groups. A similar development with 6 nylon was made by the Industrial Rayon Corporation.

In FIGURE 4 the velvet rug sample is a rug, tufted with untwist-set, all-nylon yarn. Note the objectionable appearance of rows of nylon threads in this sample. Even though the individual tufts have lost their identity to a considerable extent, the rows of yarn stand out clearly, giving the rug a "lean" appearance. The other sample, marked "twist," was prepared from a nylon rug yarn in which the twist had been well set by exposure to live steam. Note the more pleasing appearance created by the absence of

* Denier is the measurement of the fineness of filaments; the lower its denier, the finer the thread.

rows of tufts. The twist and kinks in these tufts are permanently set and persist through wear and even through rotary brushing during cleaning.

To achieve such durable setting it was necessary to spin the yarns from unset staple, that is, from staple that has never been exposed to live steam or high temperature. The yarn was then tumbled in skein form to encourage the formation of kinks. FIGURE 5 shows the appearance of such skeins before and after tumbling. After tumbling, the skeins were exposed to boiling water or live steam to set the twist and kinks permanently. Setting takes place very quickly—so quickly, in fact, that it is impossible to carry

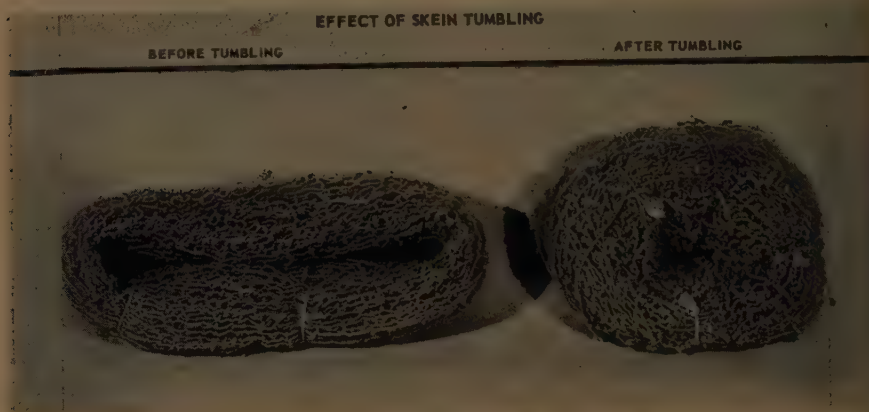


FIGURE 5



FIGURE 6

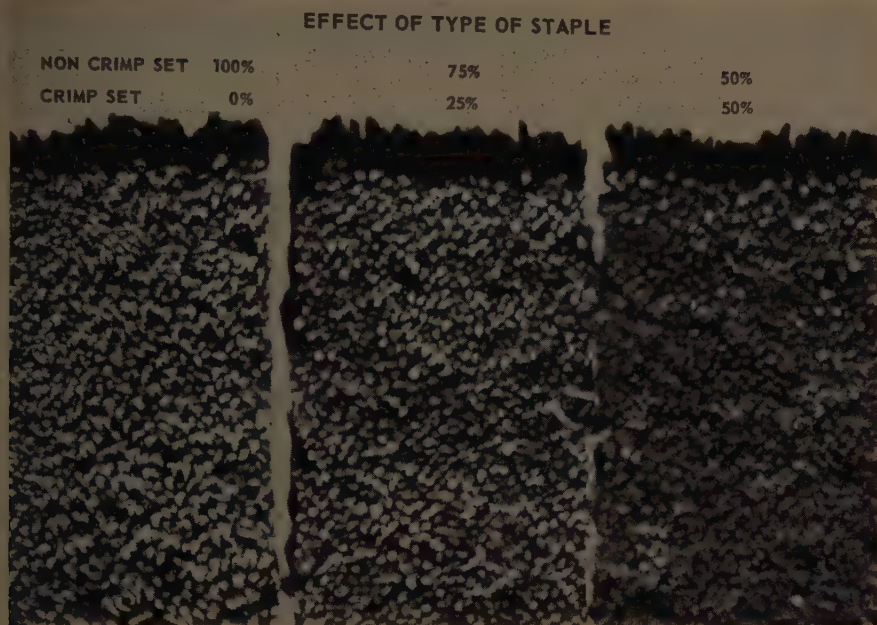


FIGURE 7

out the setting and tumbling simultaneously for, in that event, the setting occurs before sufficient kinking has time to take place.

Variations in the appearance of rugs of this type can be made by varying the twist in the yarns, by balancing the twist, or by using unbalanced twist. This effect is shown in FIGURE 6. Unbalanced twist gives a more kinky yarn and a coarser texture. The degree of twist setting can be varied by spinning the yarn from a blend of set and unset staple. This is illustrated in FIGURE 7.

Turning now to the problem of pilling, that is, the formation of balls of fiber on the surface of uncut pile nylon rugs during service, FIGURE 8 shows a badly pillied rug and another that was prepared in such a manner that it did not pill. Both have been exposed to an accelerated pilling test.

Before examining its cure, let us momentarily consider the nature of the pilling process. Pilling can occur in fabrics of all staple fibers, but it shows up most objectionably in fabrics made from fibers that are so strong and tough that the pills do not wear off during service. This is ordinarily true of nylon and polyester fibers that possess this degree of strength and toughness. Therefore, the fabrics must be so constructed and finished as to prevent the formation of the pills in the first place.

Early qualitative studies by R. S. Chapin of our Textile Research Laboratory showed that pills resulted from rising of a fuzz on the surface of the fabric, followed by self-entangling of the fibers in the fuzz to form pills. Later, D. Gintis and H. J. Mead of our Dacron Research Laboratory made a quantitative study in which the pertinent variables, namely, the density

length, and the nature of the fibers composing the fuzz were varied systematically. They found, as one might expect, that pills were not formed unless certain minimum lengths and concentrations (fibers/unit area) for the fibers in the fuzz were exceeded. These minima varied with the nature of the fibers constituting the fuzz.

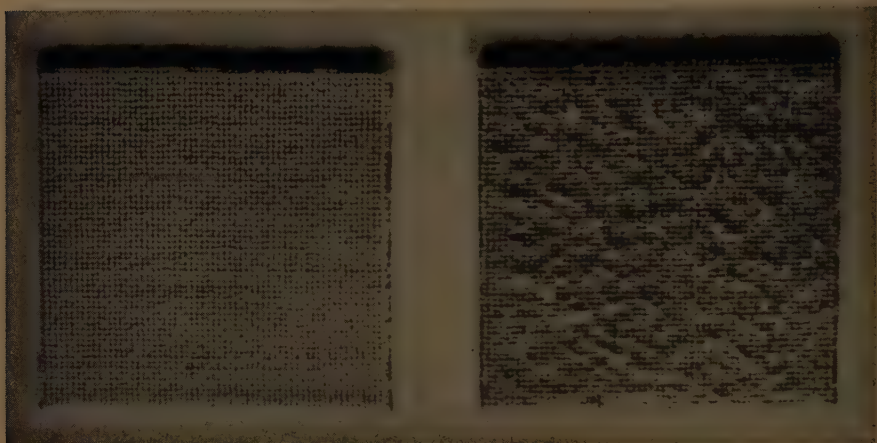


FIGURE 8. Rug samples that have been subjected to an accelerated pilling test. Sample on left had been treated against pilling; sample on right had not.



FIGURE 9. Illustration of visual rating scale for pilling. Scale ranges from 1 (no pilling) to 5 (extremely bad pilling).

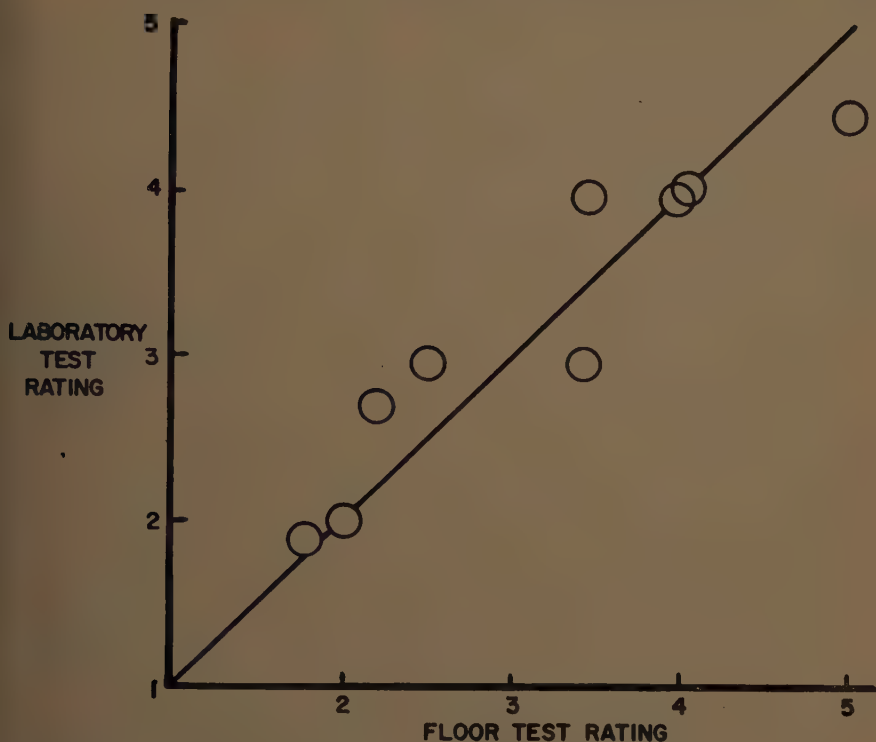


FIGURE 10. Correlation of laboratory and floor tests of nylon carpeting for pilling.

Subsequent studies showed that the relatively long fibers in the fuzz are generally formed by the pulling out of loops of filaments until one end of the filament comes loose from the yarn. As might be expected, factors such as increased twist or the application of finishes that increase frictional forces reduce the frequency with which filament loops are pulled out during service. Reasoning one step further, it should be possible to simulate the early stages of normal wear by a vigorous brushing of the fabric. This would pull out most of the filament loops that would be pulled out during normal wear. If the resulting long-lengthed fuzz were then clipped, it should be possible to prevent subsequent pilling during service.

H. E. Stanley and R. H. Pike of our Textile Research Laboratory have applied these principles to uncut-loop pile rugs. Their work is so new that this account must be regarded as a progress report. It is based mainly upon data collected during an accelerated pill test that comprised tumbling of 8-inch squares of carpet with $\frac{1}{8}$ -inch-thick rubber strips and several cloth balls (to provide lint) in a home clothes dryer for 10 hours. Pilling was graded visually on a scale ranging from 1 for no pilling to 5 for extremely bad pilling (FIGURE 9). Ratings made in this manner correlated quite well with similar ratings made on carpets exposed to the traffic of 32,000 persons (FIGURE 10).

Examination of pills formed on uncut-pile nylon rugs disclosed that many of the pill'd fibers showed evidence of having been pulled through poorly bonded sections of the backing. This suggested that, if the fibers in the loops were anchored more thoroughly by the latex applied to the backing, there might be a reduction in pilling. This was found to be the case. Many of the commercial varieties of latex have poor adhesion for nylon. A synthetic (GRS) latex gave a distinct reduction in pilling. However, this improvement alone was not enough.

Examination of nylon rug yarns spun on the woolen system disclosed that short lengths of them contained many poorly oriented nylon fibers that could be pulled out in service, even from well-anchored tufts, to form long fibers and pills. For example, when such yarns were cut into 1-inch lengths and the filaments subsequently separated, some were found to be 3 to $3\frac{1}{2}$ inches long, and 15 per cent were over $1\frac{1}{2}$ inches long. Rugs woven from this yarn pill'd severely. A comparable cotton-system yarn had only 4 per cent of fibers over $1\frac{1}{2}$ inches in length and pill'd much less. A worsted-system nylon yarn had only 2 per cent of fibers over $1\frac{1}{2}$ inches in length and produced a rug sample that pill'd hardly at all.

When rug samples that pill'd severely were subjected to 2 cycles of wire brushing to bring up these long filaments, which were then sheared, the brushed samples were found to pill much less. FIGURE 11 presents data showing the effect of both brushing and shearing and the application of an effective GRS latex. Rugs with ratings of about 2 or less are thought likely to give acceptable performance in service.

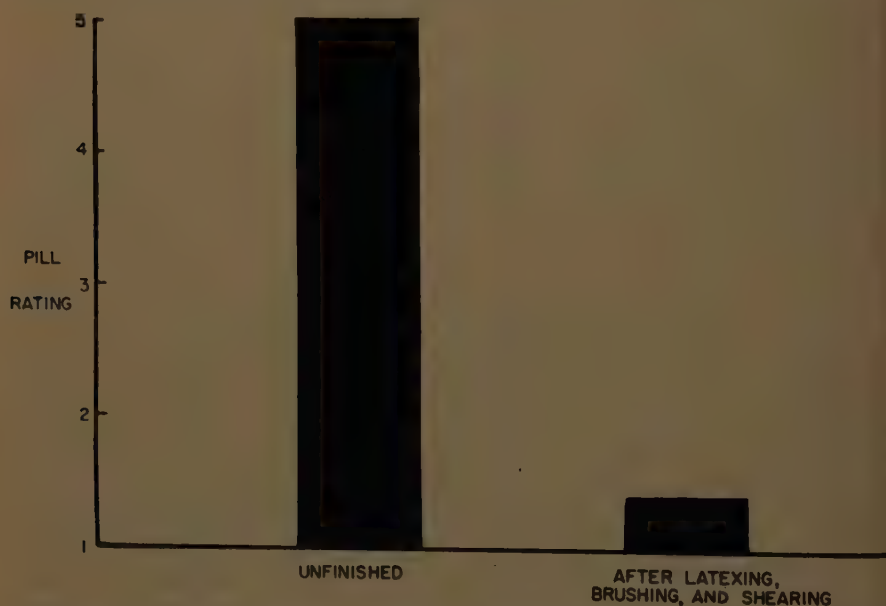


FIGURE 11. The effectiveness of treatment of carpet samples against pilling by brushing and shearing and the application of an effective GRS latex.

These and other developments in the dyeing field are eliminating the bottlenecks that formerly prevented the styling of a full line of nylon rugs. The esthetic properties of nylon rugs are beginning to approximate their superior functional properties.

Sheen Gabardine from Dacron and Rayon

Let us now consider an example that is a little more complex, one involving two fibers and the attainment of both esthetic and economic goals: that of the development of a sheen gabardine from Dacron polyester fiber and rayon. Previous to the work presented here, gabardines had been made from these fibers by blending 65 per cent of 3-denier-per-filament Dacron staple with 35 per cent of rayon staple. Constructions and finishing procedures were similar to those used on all-rayon gabardines. These fabrics pillled severely and had an unattractive hand or feel that has been described by some as "mushy," that is, too soft and deficient in liveliness. Attempts had been made to overcome these deficiencies by increasing the twist, by using plied yarns rather than singles yarn, by increasing the number of picks and ends in the fabric, and by treatment with resin. While the better fabrics resulting from these studies did not pill, they were lacking in esthetic appeal and could be described as boardy, heavy in weight, and having a "hard" handle. Also, they cost too much, largely because of the use of plied yarns.

The key to the solution of this problem lay in constructing the fabric from singles yarns spun from a blend containing mostly or all 6-denier-per-filament Dacron and subsequently finishing the fabric by close shearing and careful singeing. By using 6-denier-per-filament Dacron staple (which inherently pills less than 3-denier staple) and by very thorough shearing and singeing (if this is done, brushing is not necessary) pilling can be substantially eliminated. The heavier filament denier also improves the crease resistance, liveliness, and feel of the fabric. These effects are shown by comparing the three basic fabrics, as shown in TABLE 2. The appearance of two of these fabrics is shown in FIGURE 12. The desired economic goal was attained by using singles yarns.

High-Low Shrinkage Principle

Let us now consider a principle that greatly extends the range of esthetic effects that we can achieve by blending different fibers—the mixed-shrinkage principle. This was first applied and perfected by members of our Sales Technical Staff who were assigned the problem of making a good sweater from Orlon acrylic fiber. An improvement in bulk, cover, and hand was needed to adapt Orlon for this use.

Following several lines of reasoning, we decided to spin the yarn from a blend of two acrylic staples, one having a high shrinkage and the other almost no shrinkage. As had been hoped, when such yarn was boiled in water it increased greatly in bulk, and its hand was also improved. This combination has come to be known in the trade as high-bulk Orlon. It can be produced from either tow or staple. Its discovery played a major role

TABLE 2
SHEEN GABARDINES FROM SINGLES YARN:* COMPARISON OF THE QUALITIES OF
3 DACRON FABRICS

Denier of Dacron	Recovery (A300, %)†	Bending length‡	Subjective liveliness§	Pills per 35 sq. in.	
				unsinged	singed
3	77	1.55	5 (mushy)	283	8
4.5	80	1.77	3.5 (intermediate)	70	13
6	84	1.95	2 (not quite as good as 1)	17	0

* Spun from 65 per cent Dacron and 35 per cent rayon.

† Crease recovery measured by the Monsanto test (American Society of Testing Methods designation D 1295-53T; American Association of Textile Chemists and Colorists method 66-56).

‡ Bending length measured by the Hanging Heart test.⁷

§ The numbers under this heading are the averages of subjective ratings made by a panel of experts in which a rating of 5 represents an unwearable fabric and a rating of 1 represents perfection.

|| Pilling was measured by the Random Tumble Tester.⁸

in winning for Orlon acrylic fiber a high proportion of the sweater market.

Further studies at our Textile Research Laboratory soon showed that this high-low shrinkage principle, combined with appropriate fiber and denier blending, provided the fabric designer with a wide range of possibilities for varying the feel, cover, and bulk of fabrics woven from staple yarns.

Let us consider, for the moment, a yarn spun from a mixture of two fibers, one having high and the other low shrinkage.

When such a yarn is boiled off in yarn or fabric form, those fibers with



FIGURE 12. The effect of fiber denier on pilling. At the left (a) is a sample of a fabric constructed of 3 denier per filament Dacron; at the right (b) is a fabric constructed of 6 denier per filament Dacron. Note that there is less pilling in the latter.

high shrinkage contract in length and are drawn to the center of the yarn. Those with low shrinkage retain their length, form loops, and push toward the surface of the yarn and fabric. As a result, the fiber that has low shrinkage is the one that is felt when handling the fabric after boil-off.

Let us consider some practical examples. If one desires a lively fabric with a very soft handle, it can be achieved by constructing the fabric in the appropriate manner from a blend of low-denier staple with low shrinkage and high-denier staple with high shrinkage. Upon boil-off, the soft, fine-denier staple is forced to the surface where one can feel it. The long-denier staple, though not on the surface, functions in the core of the yarn to improve liveliness. Conversely, a crisp (referred to in the textile trade as "bitey"), tactile, tweedlike fabric can be made, using the same principle, by forcing high-denier filaments to the surface.

The two staples need not be of the same composition. For example, cotton can be forced to the surface in a Dacron-cotton blend, or wool to the surface in a Dacron-wool blend. A note of caution should be sounded in this connection, however. If the two fibers making up the blend differ widely in durability, the less durable fiber can wear away on exposed areas, thus giving rise to a change in its appearance over areas subjected to abrasion. This effect will be particularly severe if the less durable fiber has been forced to the surface and if the fibers are dyed to different shades. Consequently, the better course of action is to perfect a blend of both fibers in the surface and to control the denier of the polyester fiber in the surface in such a manner that it enhances the esthetic contribution of the second component.

This mixed-shrinkage principle can be used also to achieve substantial improvements in fabric cover, a much less thready appearance, a higher bulk and, in some cases, a substantial reduction in pilling. All of these improvements were to be expected except, perhaps, the effect on pilling. We believe that the shrinkable fibers lock the fibers in place by contracting in length and by taking a permanent set during the boil-off. This inhibits the formation of fuzz, the first step in pill formation.

In TABLE 3 are summarized measurements on 3×2 sheen gabardines made from a blend of 55 per cent Dacron polyester fiber and 45 per cent wool that show these latter effects.

TABLE 3
THE EFFECT OF FIBER SHRINKAGE ON THE PROPERTIES OF FABRICS

Boil-off shrinkage of polyester fiber component	Fabric properties		
	Thickness, in.	Bulk, cc./gm.	Pills per 35 sq. in.*
1%	.027	2.51	275
13%	.030	3.01	10

* By Random Tumble Tester.⁸

Blends

Having considered how blends of different fibers can be manipulated to control esthetic properties, it would be a mistake not to note that fabrics from certain specific blends are beginning to be recognized as having combinations of properties that can be achieved in no other way. In other words, these blends are functionally sound and not mere laboratory curiosities. In several areas the mythical "battle of the fibers" is becoming the "marriage of the fibers."

The most recent development of great importance in the industry is that of Dacron and cotton. First manufactured only four years ago, this blend is now used in millions of yards of fabrics in at least twenty-five uses ranging from ladies' dresses, blouses, and slips to men's suits, shirts, and heavy work clothing. Dacron staple, usually at least 65 per cent by volume, is blended intimately with cotton. Dacron contributes crease resistance, retention of neatness, and ease-of-care or wash-wear properties that last for the life of the garment. Cotton contributes freedom from static, as well as esthetic and styling possibilities. From the viewpoint of the wearer's comfort, the blend has an improved balance of moisture properties. The cotton increases the rate of absorption of perspiration, and Dacron adds the advantage of quick drying to minimize any feeling of dampness.

Dacron-cotton blends are also finding favor with the producers of fabrics because of the ease with which they can be dyed and finished to bright, fast shades with a most attractive hand.

The many new and attractive patterned fabrics made from these blends are illustrative of what can be produced easily by the use of yarn-dyeing techniques. The yarn is wound onto perforated stainless-steel tubes, loaded into a circulating machine, and dyed under pressure with disperse colors at 250° F. or less; and vat colors are applied subsequently to the cotton in the customary manner.

Fabrics in solid shades are dyed by a continuous Thermosol Method.⁹ Dispersed and vat colors are padded onto the fabric, which is subsequently dried in a flue dryer. It is then heated in a hot-air oven for 1 min. at 400° F. to cause the disperse colors to migrate into the Dacron. The fabric subsequently passes through a reducing bath that makes the vat dye soluble and causes it to migrate into the cotton. An oxidizing bath then develops the vat dye.

Dacron and cotton blends are finished by simple modifications of the usual cotton-finishing procedures. The fabric is first desized, scoured, mercerized, washed, dried, heat set, and singed. This suffices to prevent pilling of the Dacron in service. The subsequent finishing steps are those customarily used on cotton fabrics.

In such intimate apparel as slips and pajamas the most important fabric is a modification of this blend with a very desirable luster obtained by using a continuous-filament warp of nylon and filling it with a blend of Dacron and cotton.

Blends of nylon and cotton are coming into use, but for different reasons.

A number of very successful dress fabrics have made use of a continuous-filament warp with a cotton filling to create a fabric with an unusually attractive luster and considerable strength, despite its sheerness.

A strictly functional use is the reinforcement of cotton with 25 to 50 per cent of nylon. Thus a three-year wear test has shown that denims and twills containing 25 per cent nylon blended in the warp gave 70 per cent longer wear than similar all-cotton garments. Gloves containing 50 per cent nylon in the warp lasted on the average slightly more than twice as long as similar all-cotton gloves.

Automatic Wash-Wear

Having strayed into the area of functional performance by way of blends of nylon with cotton, I shall devote the rest of this discussion to researches that are paving the way to superior functional performance for consumers' articles made from polyamide and polyester fibers. Let us first consider the researches of R. W. Peterson, G. D. Rawlings, H. E. Stanley, and P. R. Wilkinson¹⁰ of our Textile Research Laboratory. These studies point the way to completely automatic maintenance of wash-wear garments.

These investigators studied the wash-wear performance of garments as a function of the variables of fabric construction and finishing and of washing and drying cycles. Their most startling discovery was that an ordinary household rotary dryer, operated at about 170° F., could be used as an ironing machine to remove wrinkles formed in the better wash-wear garments during washing and extraction cycles or, indeed, during actual wear.

Using an arbitrary visual scale for measuring wrinkling (FIGURE 13) these investigators showed that a tumble-drying temperature of approximately 170° F. effected the most complete removal of wrinkles without affecting the

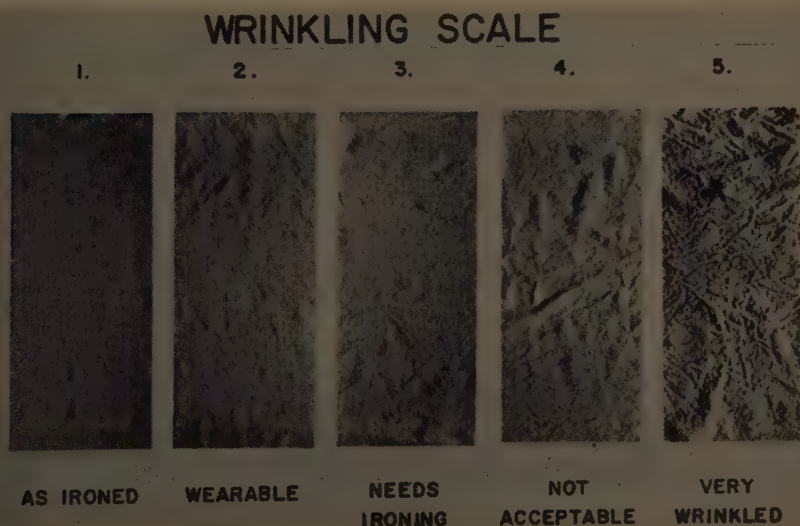


FIGURE 13

EFFECT OF TEMPERATURE DURING TUMBLE DRYING ON WRINKLING

(DATA IS AVERAGE OF 26 FABRICS)

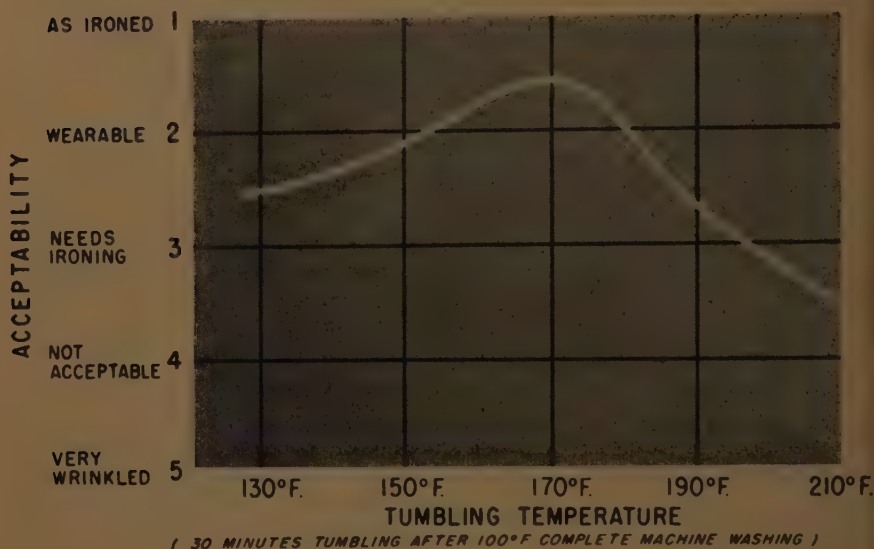


FIGURE 14

permanent creases or pleats (FIGURE 14). One half-hour of tumbling at the optimum temperature was enough to remove wrinkles caused either by wear or by the washing cycle. Good tumbling action was required, however. It was found necessary to continue the tumbling action during a 5- to 10-minute cooling cycle or else to remove the garments promptly from the dryer and hang them up to cool; wrinkling occurred if the garments were allowed to cool while piled in the dryer.

The key to the action of a tumble dryer on polyamide and polyester garments lies in the fact that the garments previously have been heat set in the unwrinkled condition by fabric finishing and pressing treatments. When the garments are tumbled at 170° F. the heat increases the rate of recovery from wrinkles imparted at low temperature during wear or washing; the tumbling flexes the fabric, overcoming the interyarn and intrayarn frictional forces that operate to prevent recovery of the individual yarns. The temperature of the dryer is not sufficiently high to "unlock" bonds formed in the fibers during the original heat setting of the fabric or during ironing. Thus, the tumble dryer offers the possibility of "pressing" not only strictly wash-wear garments, but also those made of high polyamide or polyester content that are not washed, but that have become wrinkled after repeated wear.

It is much too early to write a treatise on how to obtain optimum automatic wash-wear properties, yet we have compared enough fabrics to draw some

tentative generalizations. In the first place, Dacron polyester fiber is superior in wash-wear performance to all of the other fibers we have tested. Increasing yarn diameter, stiffness, and filament denier improve wash-wear performance of shirting-weight fabrics woven from either filament or spun yarns. Fabric constructions that permit movement of the yarns improve wash-wear performance; consequently, knits are better than woven fabrics. A marked improvement is obtained as we go from a plain weave to an Oxford weave, to a 2×2 basket weave, to a 3×3 basket weave. In loose constructions, filament yarns give more mobility than spun yarns. In blends, a concentration of at least 65 per cent Dacron is desirable.

These principles can be combined. Thus, by weaving an Oxford construction using a filament Dacron warp of 70 denier and a Dacron-cotton 40 singles spun-yarn filling, we have been able to obtain exceptionally good wash-wear performance due to the high Dacron content, the high mobility of filament yarn, and the freedom of motion of the Oxford weave. The fabric had the esthetic look and spun appearance of a broadcloth (FIGURE 15).

FIGURE 16 illustrates an automatic wash-wear suit recently unveiled by Haspel Brothers, Inc., New York, N. Y., who pioneered the first wash-wear suits four years ago. This suit contains 65 per cent Dacron polyester fiber, 25 per cent rayon, and 10 per cent mohair. Note its excellent appearance after it has been washed and tumble dried.

Throughout this discussion we have considered a wide variety of textiles

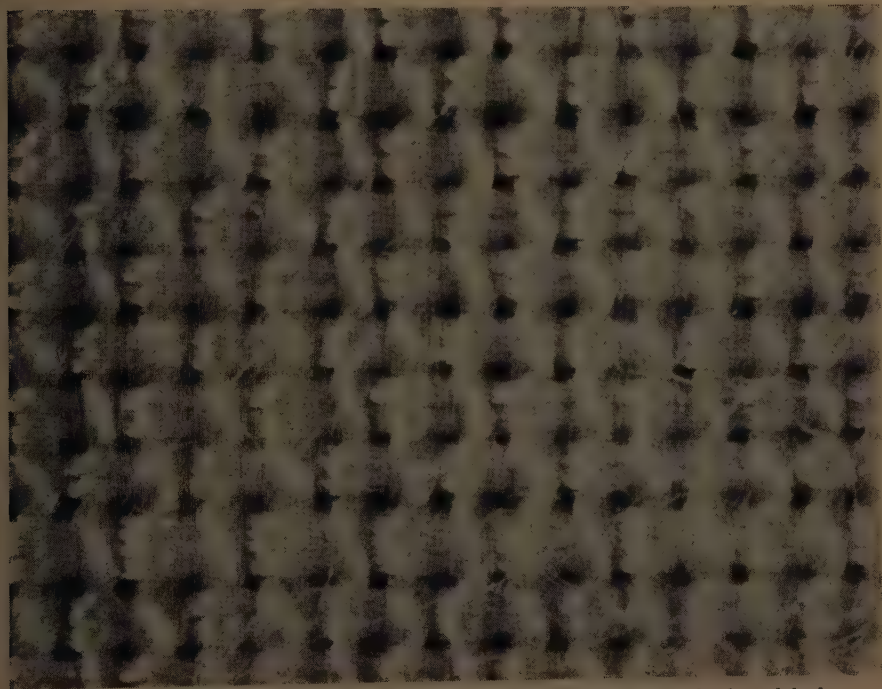


FIGURE 15. Dacron-cotton Oxford weave with the appearance of a broadcloth.



FIGURE 16. Wash-wear suit (65 per cent Dacron, 25 per cent rayon, and 10 per cent mohair) before washing (left) and after washing (right). Note excellent appearance of the suit after it has been washed and tumble dried.

made from polyamide and polyester fibers. The examples have been chosen to illustrate the many recent advances in technology that are enabling us to build into these textiles an esthetic level worthy of the superior functional properties that are much more easily achieved. It is a source of very considerable satisfaction that these advances are not being ignored by those whose business it is to familiarize themselves with the best in textiles. As evidence of this recognition I should like to quote, in closing, a paragraph taken from an article in *House Beautiful*, September 1956, page 102, entitled "The New Sophistication of Synthetics":

"In these two rooms the synthetic fabrics stand on their own merit because they are fresh, well-designed, adaptable, quite apart from their easy maintenance. They are showing the results of fruitful design experiment in their almost limitless colors, textures, patterns and weaves, frequently combined or blended with other materials. These are no esthetic misfits, for synthetics now belong, as certainly and appropriately as such old, natural standbys as silk, cotton, wool, and leather."

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ACRYLIC AND OTHER VINYL FIBERS

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On this one-hundredth anniversary of the discovery of the first synthetic dye, Mauvine, the purple gold of Sir William Henry Perkin, it is quite appropriate that the realm of fibers has been selected as the subject of this monograph. Dyestuffs and pigments are the magic ingredients that make the world of fabrics a veritable fairyland of romance and color.

In discussing recent developments in acrylic and other vinyl fibers, it seems advisable to review briefly the history of the natural and semisynthetic fibers, as well as to give a short account of the development of the first man-made fiber. The form and nature of the natural fibers have set the framework within which all subsequent developments in the fiber industry have taken place, while the basic principles discovered in the work leading to the production of nylon have been of fundamental importance in all subsequent research in synthetic fibers.

Providing the three basic essentials for life—food, clothing, and shelter—was a relatively simple task for early man. The same wild animals on which he feasted provided skins for both clothing and shelter. However, since skins were often too bulky and harsh, he searched for other materials for covering, warmth, and adornment. Centuries of patient investigation of the dozens of natural textile materials available led to the selection of four—cotton and linen from the vegetable kingdom, and wool and silk of animal origin.

The first fabrics obtained from fibers resulted from the chance observation that the loose animal hair that gathered in clumps around the fireplace had a tendency to mat together and form a crude type of felted material. This was followed shortly by the discovery of methods for the production of yarns. At Decatur, Ala., within sight of Chemstrand's Acrilan* acrylic fiber plant, the writer has found, in a prehistoric grave, copper beads containing fragments of a twisted cord. The cord contained 13 filaments and had been prepared by Indians from fibers obtained from the stem of the wild nettle about 5000 years ago.

The arts of weaving and knitting soon followed, and they became basic industries for nearly all primitive cultures. Innumerable references to such occupations are found in the folklore of all early peoples. Thus, Homer, in describing Ulysses following Ajax, says:

“As when some dapper girdled wife near to her bosom holdeth
The spindle whence she draweth out the rove beyond the sliver
So near Ulysses kept and trod the very prints of Ajax.”

Linen is probably the oldest of all textile fibers. Linen fabrics have been found in the Neolithic Swiss lake dwellings of approximately 10,000 years

* Registered trade-mark of The Chemstrand Corporation, Decatur, Ala.

ago. The manufacture of fine linen fabrics—"the cloth of kings"—was an established industry in the valley of the Nile 7000 years ago.

The early history of cotton is lost in the legends of unrecorded time, for the use of this fiber is older than history itself. The growing, spinning, and weaving of cotton was a flourishing industry in the Indus valley in India and the Nile valley in Egypt as early as 5000 years ago. In South America, the Peruvians at the time of Jesus of Nazareth were weaving luxurious cotton fabrics of a fineness that cannot be duplicated by any process known today.

Wool also was spun and made into cloth before the beginning of recorded history. The oldest evidence of the use of wool has been found in the prehistoric village of Tel Asmar in Asia Minor, which was occupied about 6200 years ago.

Silk, the last of the four great natural fibers, was first obtained from the cocoon of the silkworm perhaps 6000 years ago in China. The ancient silk-caravan route connecting China with the Middle East and Europe was an important artery of trade for over 4000 years.

These early spinners of linen, cotton, wool, and silk laid the basis for the synthetic-fiber industry of today, and they directed the pattern of its development to an extent not commonly realized. With the exception of tow and the larger monofilaments, which account for only a small proportion of the total production of synthetic fibers, all such fibers are made closely to resemble either cotton or woolen staple fibers or the continuous-filament yarns spun by the silkworm. Centuries of patient effort have been required to bring the equipment used for the conversion of natural fibers to yarns and fabrics to its present high level of efficiency. To find a place in the textile industry, synthetic fibers must possess, as closely as possible, the processing properties of the natural fibers.

Until late in the last century, the fine fibers so generously provided by nature were available in sufficient quantities to meet all requirements for textiles. However, with the further development of the Machine Age, with its emphasis upon productivity and the large-scale manufacture of what had once been regarded as luxury items, an insatiable appetite for more and better textiles was created. The feminine wardrobe, which had been restricted to articles of the commoner fibers for all but the favored few, now demanded increasing quantities of costly and exotic garments.

As demands increased, certain limitations of the natural fibers became apparent. The supply of silk and linen, the traditional luxury fibers, was limited and could not be increased substantially. New types of fibers produced by the genius of man were evolved to satisfy these pent-up demands. Possessing many desirable properties, they have long since won recognition and a permanent place in our textile economy. Their development has resulted in a general improvement in all textiles as the producers of natural fibers, determined not to be outdistanced completely by these upstarts from the laboratory, have redoubled their efforts to improve the style, quality, and serviceability of the older materials.

The brilliant British physicist Robert Hooke predicted the eventual

development of artificial silk nearly 300 years ago. Recognizing that the basic problem was the provision of a suitable "artificial glutinous composition—much resembling that out of which the silkworm wiredraws his clew," he stated that "if such a composition were found, it were certainly an easy matter to find very quick ways of drawing it out into small wires for use . . . I need not mention the use of such an invention nor the benefit that is likely to accrue to the finder, they being sufficiently obvious."¹

While we may question Hooke's designation of the development of suitable spinning techniques as an "easy matter," his procedure still serves as a blueprint for the development of new fibers. Then, as now, the problem resolves itself into the basic steps of (1) providing a composition having the desired chemical and physical properties, and (2) shaping the composition into filaments of the required size and shape.

Despite this promising beginning, very little progress was made during the next two centuries, primarily because it was necessary for the science of chemistry to advance to the point at which it could supply the "artificial glutinous composition" required by Hooke's process. In 1883, Edward Weston² produced experimental filaments from an ether-alcohol solution of nitrocellulose and, shortly thereafter, Sir Joseph Swan² found that the product could be denitrified by the action of ammonium sulfide, thus regenerating the cellulose. The stage thus was set for the production of an artificial fiber, although the basic raw material had been provided by nature's marvelous process of photosynthesis instead of in the chemist's test tube.

Count Hilaire B. de Chardonnet² then bent his keen mind to the task in the closing years of the past century. A chance observation of a sphaggetti machine extruding a plastic mass in the form of large filaments led him to the conclusion that a synthetic fiber could be produced if a solution of the proper composition were forced through minute orifices. After many false starts, the Weston-Swan process for the regeneration of cellulose was adopted, with promising results. This led to the construction of the first plant for the commercial production of rayon at Besançon, France, in 1891. Sold under the name of artificial silk, the product was an instant success in a world hungry for a larger volume of luxurious fabrics than could be derived from the limited output of the silkworm.

Having started to compete with nature in the production of fibers, man found it necessary to follow nature's blueprints with respect to the size and shape of the new filaments. It was also necessary to become accustomed to working in a world having new dimensions with respect to size and quantity, for the textile field deals with infinitely small quantities of matter in infinitely large numbers. For example, a pound of one-denier, one-inch staple contains about 180 million individual fibers which, if placed end to end, would extend for nearly 3000 miles. In processing on a cotton card, each fiber will be subjected to approximately 3 million combing operations, and carding is only one of the many operations required to convert fibers into spun yarns, fabrics, and garments.

While fibers vary widely in their physical characteristics, they have one important property in common—all true fibers are quite long with respect

to their breadth. Among fibers commonly used in fabrics, the length: breadth ratio varies from 1000:1 in the case of cotton to over 30 million:1 in the case of silk. As a general rule, therefore, it may be said that fibers, to be useful commercially, should have a length: breadth ratio of at least 1000:1.

In manufacturing operations, it was soon found that the shape of the fiber could be varied by suitable changes in the techniques of spinning, and that such variation would influence the physical and chemical properties of the resulting yarns and of the fabrics made from them. In order to produce a uniform fiber, it was necessary to control closely a large number of variables in spinning. Thus, in the spinning of viscose rayon, changes in the spinning procedure may produce fibers having flatter cross sections than usual. The use of such fibers in the manufacture of materials will result in bright spots in the fabric due to better light reflectance.

In general, it may be said that flat yarns have a high luster and excellent covering power, but a harsh hand. A yarn with a circular cross section, however, has a good hand, but poor covering power. Due to the large surface exposed to the dye bath, serrated yarns are more readily dyeable.

Since rayon was originally manufactured as a substitute for natural silk, it was produced until about 25 years ago only in the form of continuous-filament yarns. Additional work had shown that rayon would have good possibilities for use in competition with cotton, so processes were developed for the manufacture of rayon staple. The fiber so produced was made to conform to the specifications of cotton with respect to denier and length of staple.

Produced in this way, rayon staple had an important advantage over cotton with respect to uniformity. Cotton and all other natural fibers vary considerably in denier and length of staple, while rayon tow can be made in any desired denier and cut to any required length. The idea of tailoring fibers to meet the requirements of specific end uses was beginning to pervade the industry.

In 1930, E. I. du Pont de Nemours & Company, Inc., Wilmington, Del., undertook to develop a tough, high-tenacity rayon yarn for use in tires and for other industrial purposes. An improved yarn was developed and successfully manufactured, but the most important result of the work was the attention it focused on the need for fundamental research in the fiber industry. High polymers other than those naturally present in cellulose and proteins were required if the manufactured-fiber industry were to attain its full potentialities.

The first real insight into the structure of matter comprising fibrous bodies resulted from the X-ray diffraction experiments carried out by Laue and Bragg.³ These studies showed clearly that the molecules that make up cotton, wool, and other fibers are also very long and narrow, which is to say that they are fibrous in nature. Just as reasonably long fibers are required to spin a satisfactory yarn, long, narrow molecules are required for the production of a good fiber. Measurements on cotton show that the length: breadth ratio of the cellulose molecules in a typical fiber is approximately 7000:1, which is of the same order of magnitude as the length: breadth

ratio of the fiber itself. The X-ray data also show clearly that cotton is crystalline in nature, and that it has a simple repeating pattern corresponding to the dimensions of a glucose unit.

Once it had been clearly established that molecules must be long and thin to possess fiber-forming properties, chemists were quick to grasp the possibilities of constructing such molecules in the laboratory from simple chemical building blocks to form true synthetic fibers. However, the problem of providing these threadlike molecules was a very difficult one, as earlier experiments had produced materials so intractable that they had been invariably discarded.

In the interim, Wallace Hume Carothers had joined Du Pont and been given a free hand in selecting his field of work.⁴ With true genius, he reasoned that these insoluble, infusible, noncrystalline, unreactive materials discarded by others resembled the raw materials from which fibers might be spun more closely than did the products of more orderly experiments. He resolved to work in the field of high polymers.

His classical researches into the mechanism of the formation of high polymers presented a clear picture of the processes involved in the production of linear polymers from simple chemical compounds. While such polymers can be made by addition polymerization methods that involve the union of several molecules with a redistribution of the valency bonds, but with no loss of materials, he worked mainly in the field of condensation polymers, in which several monomeric units are joined by the elimination of a structural unit, such as water. This led directly to the production in 1935 of a linear polyamide (nylon 66) from adipic acid and hexamethylene diamine. The polymer was melt-spinnable and could be oriented readily by cold drawing to give lustrous fibers of good strength and flexibility.

Drawing the spun fiber brings about a very desirable molecular change that consists of a gradual rearrangement of the long molecular chains from their unoriented, random arrangement to one in which the long chains are made to parallel each other and are brought very close together. This makes it possible for strong intermolecular forces to be brought into play, resulting in a progressive increase in tensile strength. This concept of drawing is of the utmost importance to the fiber technologist, as it makes it possible, by varying the draw ratio, to prepare a family of fibers varying from weak and limp to strong and stiff from the same lot of undrawn fiber.

At the same time, this technique must be used with caution, as overdrawing can lead to undesirable results for certain end uses of fiber. Properties imparted to fibers by deep drawing include high tenacity, low elongation, brittleness, increased luster, low moisture absorption, high chemical stability, low dyeing affinity, and an unattractive hand. These properties are developed to varying degrees, depending upon the chemical make-up of the fiber molecules, its molecular weight, and the conditions under which the drawing is performed.

I have already called attention to the fact that there is a close resemblance between the shape of a given fiber and the shape of the molecules of which it is composed. Similarly, the process of drawing is analogous to the pro-

cedures used to convert staple fibers to yarns, a process in which the fibers are first rendered parallel and then twisted to prevent the fibers from sliding over each other when a longitudinal force is applied to the yarn. In drawing, the fiber molecules are made to parallel each other and brought closer together; secondary valence and van der Waals' forces then act in the same manner as twist in spun yarns to prevent the molecules from sliding past one another upon the application of longitudinal force.

This pioneering work made it possible to list some of the properties that a high polymer should possess in order to be fiber forming, namely: (1) it should have a molecular weight exceeding 10,000 and an average chain length of over 1000 Å.; (2) it should be linear in nature, possess a high degree of symmetry, and have no bulky side groups to interfere with orientation; (3) it should be capable of undergoing a high degree of orientation in order to develop strength on drawing; and (4) the polymer chains should have a high degree of polarity, produced by polar groups evenly spaced in the chain, to produce an intermolecular cohesion sufficient to lead to a high melting point and the ability to maintain induced orientation.

This discussion of the historical development of synthetic fibers has been given in some detail in order to serve as an introduction to the consideration of acrylic and vinyl fibers. The information acquired by fiber technologists during this period of basic research was of great assistance in the development of commercial fibers from acrylonitrile and various other vinyl compounds, and in understanding the problems encountered in the general area of the production of fibers.

Acrylic and Vinyl Fibers

Nearly half a century has passed since the first vinyl fiber was described in the literature. Laboratory work performed in Germany in 1910⁵ on the polymerization of vinyl chloride led to the production of polyvinylchloride fibers on a laboratory basis. However, the fiber was no more than a laboratory curiosity since its physical properties were entirely inadequate to meet any commercial requirements. About 20 years were to pass before the science of polymer chemistry advanced to the point at which polymers having properties that would make them suitable for commercial fiber-spinning operations could be prepared. An even longer time was to pass before the science of fiber formation from chemical polymers had developed sufficiently to permit fibers having satisfactory physical and chemical properties to be spun from such polymers.

It was long recognized that the vinyl compounds offered a fruitful field for work in the development of fiber-forming polymers. The monomers can be prepared readily by relatively simple means from cheap and abundant raw materials. The majority of the vinyl compounds of any commercial importance in the polymer field can be prepared from petroleum, natural gas, chlorine, and ammonia. These monomers can be purified without difficulty and, because of their reactive nature, they can be converted readily to polymers having a wide variety of physical and chemical characteristics. Finally, a number of vinyl polymers had been developed for use in the plastics

TABLE 1
PUBLISHED PHYSICAL PROPERTIES OF REPRESENTATIVE ACRYLIC AND VINYL FIBERS

Fiber	Chemical type	Manufacturer	Form*	Tenacity grams/ denier	Relative wet tenacity†	Elongation %	Elastic modulus grams/denier	Density
1. ACRYLIC								
Acrilan	Acrylic	Chemstrand	S	2.5	80	36	7-8	1.17
Creslan	Acrylic	American Cyanamid	S	2.7-3.5		33-40		1.17
Orlon 42	Acrylic	du Pont	S	2.2	83	25	5-9	1.14?
Orlon 81	Acrylic	du Pont	CF	5.5	95	17	26-39	1.14
Verel	Acrylic	Tennessee Eastman	S	2.5-3.0		33-35		1.15
Zefran	Acrylic	Dow	S					
2. VINYL								
Darlan	Vinylidene cyanide	Goodrich	S	1.75	86	30		1.18
Dawbarn	Polystyrene	Dawbarn	CF	2.0	100	40		1.05
Pe Ce	Afterchlorinated vinyl chloride	I.G. Farbenindustrie (Germany)	CF	1.8-2.2	100	40		1.54
Reevon	Polyethylene	Reeves Bros.	M	6-9	100	10-25		0.95
Rhovyl	Vinyl chloride	Soc. Rhovyl (France)	S	3	100	12	28	1.4
Saran	Vinylidene chloride	Dow	S	1.5	100	15-25		1.7
Teflon	Tetrafluoroethylene	du Pont	CF	1.7	100	13	9	2.3
Vinyon	Polyvinyl alcohol	Kurashiki (Japan)	S	2-6	75	15-30	20-110	1.3
Vinyon HH	Vinyl chloride	American Viscose	S	0.7-1.0	100	125	28-38	1.34
	Vinyl acetate							
3. VINYL-ACRYLIC								
Dynel	Vinyl-acrylic	Carbide & Carbon	S	2.5-3.3	100	30-42		1.3

* S = staple, CF = continuous filament, M = monofilament.

† Expressed as per cent of dry tenacity.

TABLE 2
OTHER PUBLISHED PROPERTIES OF REPRESENTATIVE ACRYLIC AND VINYL FIBERS

Fiber	Thermal properties* °F.	Water absorbency %	Sun-light resist- ance	Chem- ical resist- ance	Dyestuffs
1. ACRYLIC					
Acrilan	S = 455	1.2	Good	Good	Acid, chrome, acetate, basic, vats, metalized
Creslan	S = 400	1.5	Good	Good	
Orlon 42	S = 455	1-2	Good	Good	Basic, acetate, vat
Orlon 81	S = 450+	1	Good	Good	Difficult to dye
Verel	S = 300	4		Good	Acetate, basic, premetalized
Zefran					
2. VINYL					
Darlan	S = 340	2-3			Dispersed, cationic, vat
Dawbarn	S = 230-350				Difficult to dye
Pe Ce	S = 212	0.1		Fair	
Reevon	S = 210	0.1	Good	Fair	Difficult to dye
Rhovyl	MP = 293	0			Acetate, naphthols, indigosols
Saran	S = 280	0.1	Good	Fair	Difficult to dye
Teflon	S = 500+	0	Good	Excellent	Difficult to dye
Vinyon	S = 395	5		Good	
Vinyon HH	S = 170	0.1	Good	Fair	Dispersed
3. VINYL-ACRYLIC					
Dynel		0.4	Fair	Excellent	Acetate, acid, direct, basic, vat

* Symbols: S = softening point; MP = melting point.

TABLE 3
OUTSTANDING FIBER, YARN, AND FABRIC PROPERTIES

Properties	Fiber types
Over-all mechanical performance, including processing	Acrylics, polyvinylchloride, Vinyon
Hand	Acrylics
Bulk	Acrylics, polyvinylchloride
Low friction	Polyethylene, Teflon
Heat resistance	Teflon, acrylics
Nonflammability	Polyvinylchloride, Saran, Dynel
Sunlight resistance	Acrylics
Chemical resistance	Teflon
Electrical properties	Polyethylene, polystyrene
Dyeability	Acrylics, Vinyon

and synthetic rubber fields before much attention had been given to their possible use in synthetic fibers.

Once undertaken, the development of fibers from acrylonitrile and other vinyl compounds took place in a rather orderly fashion. Prior experience with these substances in plastics and synthetic rubber served as a guide in the preparation of the required polymers, and the knowledge acquired in spinning the cellulosic fibers was used to direct the course of the spinning operations. It must not be assumed, however, that these procedures served as a complete blueprint for the preparation of acrylic and other vinyl fibers. It was necessary to overcome many difficulties before polymers having the required properties could be prepared, and entirely new concepts in spinning were necessarily developed before a satisfactory vinyl fiber was produced.

As many vinyl compounds were commercially available at the beginning of this investigation, and as a host of additional compounds could be prepared readily in the laboratory, considerable attention was given to the selection of the monomers to be used. Representative aliphatic, aromatic, and heterocyclic vinyl compounds had been converted to polymers in prior work in other fields; an evaluation of the results obtained indicated that the simple aliphatic vinyl compounds were best adapted to the requirements of the fiber industry. Time has proved that this initial selection was fundamentally sound. With only minor exceptions, the vinyl fibers that have met commercial acceptance began as simple unsaturated aliphatic compounds.

This state of affairs may not continue indefinitely, however, as new polymerization procedures and spinning techniques have made it desirable to re-evaluate the monomers previously discarded. Polystyrene fibers are in limited commercial production abroad, and the use of certain heterocyclic vinyl compounds as comonomers with other vinyl compounds has given promising results in certain cases.

Polymerization. The first fiber-forming synthetic polymers were homopolymers obtained by the polymerization of a single reactive monomer. While the physical properties of a fiber produced from a given monomer can be altered to some extent by varying the molecular weight and molecular-weight distribution of the polymer to be spun, it is nonetheless true that only one fiber can be obtained. However, the number of fibers that can be produced from a given number of monomers was to be increased in a spectacular manner by a fundamental discovery in the polymer field.

In the 1930s, scientists of the Carbide and Carbon Chemicals Corporation, New York, N. Y., began to investigate the production of synthetic fibers from the simple vinyl compounds. Following the lead of the earlier German workers in this field, their scientists prepared polyvinylchloride and spun it into fibers. While a large number of such polymers prepared by widely different polymerizing techniques were investigated, the resulting fibers invariably were brittle and weak. Polymers prepared from vinyl acetate melted at too low a temperature to be considered seriously for this purpose, and mixtures of polyvinylacetate and polyvinylchloride did not produce commercial fibers of any value. However, when the two monomers were mixed and polymerized, the resulting copolymer offered good possi-

bilities as a basis for fibers. In 1939, the American Viscose Corporation, Marcus Hook, Pa., produced the first fibers from this vinyl chloride-vinyl acetate copolymer on a commercial scale under the trade-mark "Vinyon."

This solution to the problem of producing a satisfactory vinyl fiber from a given original material by copolymerization with another monomer had a far-reaching effect upon the expanding synthetic-fiber field. By a suitable choice of comonomers, and by varying the proportions used, fibers having a wide range of physical and chemical properties could be prepared from relatively simple materials. At the same time, this posed a challenge to the fiber and polymer chemist; by proper permutations and combinations, a half-dozen reactive comonomers could be made to yield an almost infinite variety of end products. As time and equipment are limited, and experimentation is always costly, it became even more necessary, from a technical standpoint, to direct the work in a given fiber field carefully, in order to develop a commercial fiber within a reasonable period of time.

In both the homopolymer and copolymer areas, fundamental advances in general polymerizing procedures and techniques have made it possible more closely to control the polymerizing reaction and thus to regulate the molecular weight and the molecular-weight distribution within very narrow limits. The discovery of the reduction-oxidation (redox) catalysts just prior to World War II and their extensive use in the rubber and plastics industries provided a firm base from which important advances in the area of fiber polymers could be launched in a relatively short period. The development of continuous polymerizing processes, in conjunction with methods for achieving this at relatively low temperatures, led to the production of polymers having a purity much greater than that obtained by earlier procedures. This purity, in turn, has made it possible substantially to improve certain properties, such as color and hand, of the acrylic and vinyl fibers.

A further development was the production of polymer blends, in which mixtures of homopolymers or copolymers, or both, could be used for the preparation of new alloy-type fibers. As in the case of copolymers, certain unexpected results have been obtained with these mixtures, particularly with respect to the physical properties of the fibers derived from them. As the softening point of a fiber is an important factor in the production of garments that must withstand normal ironing temperatures, the discovery that certain polymer blends produced fibers having higher softening points than could be obtained from copolymers having the same composition proved valuable. A large number of such polymer blends have been evaluated, and some have produced particularly interesting results. Some of the processes combine synthetic polymers with natural polymers or modified natural polymers. An example is the work carried out by the Textile Research Institute, Princeton, N. J., on blends of polyacrylonitrile and cellulose acetate.

These blending procedures are used in the production of the so-called alloy-type fibers that are being evaluated by a number of companies. It is expected that they will become increasingly important as the trend toward the production of specific types of fibers for definite end uses becomes more

pronounced. With the possibilities inherent in blending homopolymers, copolymers, natural polymers, and modified natural polymers, the number of fibers that can be made is limited only by the time and patience of the experimenter.

A fundamental development in the polymer field, and one of particular importance to the fiber chemist, has been the synthesis of block and graft copolymers. Whereas binary copolymers of monomers *A* and *B* may have either an ordered



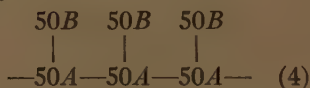
or random



configuration, block copolymers of *A* and *B* contain long alternating stretches of *A* and *B*



while graft copolymers prepared from the same monomers contain blocks of one of the monomers as a backbone, with branches made up of blocks from the other monomer



It is immediately apparent that the configurations of copolymers (1) and (2) are essentially different from those of copolymers (3) and (4). It is further evident that such differences are of sufficient magnitude to impart radically different properties to the latter two copolymers and to the fibers subsequently obtained from them. These differences have been verified experimentally, thus opening up a new avenue of approach to the production of acrylic and vinyl fibers possessing entirely new physical and chemical properties.

In ordered or random copolymers, the blending of the two constituents is very intimate in nature, since the change from *A* to *B* occurs on a micro-molecular scale. As a result, the properties of such copolymers are, essentially, averages of the corresponding properties of the two components. Thus, if *A* is an oil-soluble monomer, such as styrene, and *B* is a water-soluble monomer, such as vinyl alcohol, the resulting regular or random copolymer will be soluble in solvents of intermediate polarity, such as dioxane.

Block and graft copolymers, on the other hand, represent a much coarser mixture of components *A* and *B* than is obtained in ordered or random copolymers. To a certain extent, the individual sequences, or blocks, of *A* and *B* display some of the characteristics of the corresponding homopolymers of *A* and *B*. As a consequence, certain properties of the copolymers described in EQUATIONS 3 and 4 should represent a superposition of the properties of polymer *A* and polymer *B*, rather than an average of such properties.

Results have tended to confirm this hypothesis. Thus, a graft copolymer of styrene and vinyl alcohol containing a backbone of 500 styrene units and 20 branches of 25 vinyl alcohol units each is soluble in both water and toluene. In water, the polyvinylalcohol branches are readily dissolved or solvated, with the result that the insoluble styrene segment, being chemically linked

to the solvated or dissolved polyvinylalcohol units, is maintained in a state of stable suspension.

If the same copolymer is placed in toluene, the polystyrene trunk is readily dissolved, while the polyvinylalcohol branches collapse on each other and are maintained in a state of stable suspension by their chemical attachment to the dissolved polystyrene trunk.

Thus, in either water or toluene, one half of the graft copolymer may be regarded as being dissolved, while the other is precipitated. In a liquid that is a solvent for both components, however, such as a mixture of water, dimethylformamide, and toluene, and segments of the polymer, both trunk and branches, are solvated, and the entire polymer is dissolved.

Block copolymers may be obtained in a two-step operation that involves the preliminary preparation of polymer *A* and polymer *B* in separate reactions in such a way that each polymer contains reactive groups at both ends, followed by the combination of the two fractions and the continuance of polymerization in the presence of a suitable bifunctional linking agent. The blocks of polymer *A* and polymer *B* are then connected and form a polymer that contains the desired sequence of polymer *A* and polymer *B* units, the actual composition being regulated by the polymerizing conditions employed in each step of the operation.

As an example, the polymerization of styrene at low temperatures with hydrogen peroxide and ferrous sulfate results in linear polystyrene molecules having a hydroxyl group at each end. By the use of appropriate concentrations of styrene, catalyst, and activator, the number of styrene units in the polystyrene blocks can be regulated at will. Polymethacrylate blocks then are prepared in a similar manner, after which the two polymers are mixed and linked together with a diisocyanate to form a linear block copolymer.

Two general methods have been used to form graft copolymers. In the first, polystyrene is prepared and oxidized lightly to form a series of —OOH groups dispersed in an essentially random fashion along the polystyrene chain. Vinyl alcohol then is added, together with a redox activator such as ferrous gluconate. The ferrous ions react with the hydroperoxyl groups to produce free radicals, all of which are attached to the polystyrene trunk. As a result, the polymerization of the vinyl alcohol is restricted entirely to the formation of polyvinylalcohol branches on the polystyrene backbone. Of course, other monomers can be used in place of styrene and vinyl alcohol to give a variety of graft copolymers.

As an example of the second procedure, a copolymer of styrene and from 1 to 2 mol per cent of vinyl acetate is prepared in methyl ethyl ketone solution. Due to the difference in the relative reactivity of the two monomers, the vinyl acetate units are isolated and attached at widely spaced intervals along the polystyrene chain. The acetate then is hydrolyzed to form hydroxyl groups, followed by the addition of ethylene oxide and a continuation of the polymerization. Under these conditions, all of the ethylene units are attached as chains to the polystyrene trunk. As in the preceding procedure, a wide variety of graft copolymers can be prepared by this method.

The development of block and graft copolymers is of outstanding importance to the fiber chemist working with the acrylics and vinyls. The very

desirable properties of these fibers have recommended their use in many applications in clothing, but certain limitations of the fibers with respect to dyeing and static problems have retarded their use in certain other fields. These difficulties have been met, in most part, by the preparation of copolymers and their use as such, or in admixture with other polymers or copolymers, to prepare fibers having improved dyeing and static characteristics. The graft-and-block technique will make it possible to modify even further the acrylic and vinyl fibers in these and other respects to an extent that has not been possible heretofore. A whole new spectrum of fibers possessing outstanding properties for use in certain specific applications should result, thus bringing nearer the day when fibers can be tailored to fit definite end uses.

Another important development in the realm of fiber polymers is the discovery of procedures by which vinyl compounds, including the simple olefines such as ethylene and propylene, can be converted to symmetrical polymers of greatly improved crystallinity. These polymers are known as isotactic polymers, and they can be spun into fibers having very good mechanical and thermal properties. The processes for the production of isotactic polymers were developed mainly by Schildknecht and Alfrey⁶ in this country, by Ziegler⁷ in Germany, and by Natta^{8a,8b} in Italy.

The process involves the use of certain catalysts known as stereospecific catalysts; the polymer molecule grows on the catalyst surface to form long straight chains. A number of different catalyst systems have been proposed; the following may be considered as representative:

- | | |
|---|-----|
| An aluminum alkyl + titanium chloride | (1) |
| Lithium alkyl (which may be supported) | (2) |
| Alfin catalyst (sodium alkyl, sodium alkoxide, sodium chloride) | (3) |
| Certain hydroforming catalysts | (4) |

The polymerization proceeds to form long, threadlike polymers substantially free from branching. They are related structurally to the stereo (DL) forms of certain organic compounds possessing optically active carbons in the chain. Thus, in the case of the isotactic propylene polymer, the methyl groups are all located on the same side of the polymer chain, thus imparting a highly crystalline character to the molecule. This structure is in contrast with the amorphous nature of polyisopropylene produced by more conventional methods.

The implications of this procedure are of great importance to the fiber technologist because it affords him the opportunity of making very strong fibers with high melting points from relatively inexpensive and readily available raw materials. As a result, a very substantial amount of work is being carried out in this country and abroad on the production of polyethylene, polyisopropylene, and polystyrene fibers from the corresponding isotactic polymers. While many problems remain to be solved, particularly in spinning operations, it is to be expected that a number of industrially important fibers will be developed as a result of this new concept in the polymer field.

TABLE 4
LIST OF ACRYLIC AND VINYL FIBERS

Fiber type	Form*	Manufacturer	Location	Trade name
Acrylic	Under development	Fabelta (Union des Fabriques Belges de Textiles Artificiels S.A.)	Zwijnaerde, Belgium	Acrybel
Acrylic	C S	du Pont Company of Canada, Ltd.	Maitland, Ont., Canada	Orlon
Saran	M	Firestone Tire & Rubber Company of Canada, Ltd.	Hamilton, Ont., Canada	Velon Saran
Saran	M	Richmond Plastics, Ltd.	Richmond, P. Q., Canada	Saran
Acrylic	C S	Société Crylor	Vénissieux (Rhône), France	Crylor
Polyvinyl-chloride	C S	Société Rhovyl	Tronville-en-Barrois, France	Rhovyl, Thermovyl, Crinovyl, Fibravyl, Isohyl, Clorene
Acrylic	C	Farbenfabriken Bayer A.G.	Dormagen, West Germany	Pan (probably discontinued)
Acrylic	S	Farbenfabriken Bayer A.G.	Dormagen, West Germany	Dralon
Acrylic	S	Phrix Werke A.G.	Hamburg-Neumünster, West Germany	Redon
Acrylic	S	Süddeutsche Zellwolle A.G.	Kelheim/Donau, West Germany	Dolan
Polyvinyl-chloride	S	Deutsche Rhodiace A.G.	Freiburg/Breisgau, West Germany	PeCeU, Rhovyl
Saran	Unknown	Bolta Werke G.m.b.H.	Nürnberg, West Germany	Vestan
Saran	Unknown	Internationale Galalith Gesellschaft m.b.H.	Hamburg-Harburg, West Germany	Vestan
Acrylic	S	VEB Filmfabrik AGFA Wolfen	Wolfen, Kreis Bitterfeld, East Germany	Wolcrylon
Acrylic	S	VEB Kunstseidenwerk "Friedrich Engels"	Premnitz, Kreis Rathenow, East Germany	Prelana
Polyvinyl-chloride	C	VEB Filmfabrik AGFA Wolfen	Wolfen, Kreis Bitterfeld, East Germany	PeCe, PCU
Saran	M	The United Saran Plastic Corporation, Ltd.	Rehovot, Israel	Saran
Polyvinyl-chloride	C S	Polymer Industrie Chimiche	Terni, Italy	Movil
Polyvinyl-chloride	Unknown	Montecatini Società Generale per l'Industria Mineraria e Chimica	Milan, Italy	Moviret
Acrylic	S	Kanegafuchi Boseki KK	Hyogo, Takasago, Japan	Kanekalon K, Kanekalon N
Acrylic	In development	X-lan Industry Company	Nihama or Osaka, Japan	X-lan
Polyvinyl-chloride	C S	Teikoku Jinzo Kenshi KK	Iwakuni, Japan	Tevilon
Saran	M	Asahi-Dow, Ltd.	Suzuka, Japan	Saran
Saran	M	Kureha Boseki KK	Inagawa, Japan	Kurehalon
Vinyon	S	Dai Nippon Boseki KK	Sakoshi, Japan	Mewlon
Vinylidene cyanide	In development	Nippon Geon Company, Ltd.	Niigata, Japan	Daran
Vinyon	S	Kanegafuchi Boseki KK	Yodogawa, Japan	Kanebian
Vinyon	S	Kurashiki Rayon KK	Kurashiki and Okayama, Japan	Cremona, Kuralon
Vinyon	S	Mitsubishi Rayon KK	Otake, Japan	Vinylan
Vinyon	S	Nippon Gosei Sen-1 KK	Ogaki, Japan	Woolon
Vinyon	S	Toyo Boseki KK	Iwakuni, Japan	Iwakuni
Acrylic	S	N.V. Kunstzijdespinnerij Nyma	Nijmegen, The Netherlands	Nymcrylon, Nymeron
Saran	M	N.V. Hollandsche Draaden Kabelfabriek	Amsterdam, The Netherlands	Draka Saran
Acrylic	C S	Stockholm Superfosfat Fabriks AB	Stockholm, Sweden	Akryl

TABLE 4 (Continued)

Fiber type	Form*	Manufacturer	Location	Trade name
Acrylic	S	Chemstrand Limited	Coleraine, Northern Ireland	Acrilan
Acrylic	S	Courtaulds, Ltd.	Coventry, Warwickshire, United Kingdom	Courtelle
Polyethylene	C	Courtaulds, Ltd.	Coventry, Warwickshire, United Kingdom	Courlene
Polyvinyl-chloride	S	B.X. Plastics, Ltd.	Chingford, London, United Kingdom	Bexan
Saran	M	B.X. Plastics, Ltd.	Chingford, London, United Kingdom	Saran
Acrylic	S	American Cyanamid Company	Near Pensacola, Fla.	Creslan
Acrylic	S	The Chemstrand Corporation	Decatur, Ala., United States	Acrilan
Acrylic	S	Dow Chemical Company	Lee Hall, Va., United States	Zefran
Acrylic	S	E. I. du Pont de Nemours & Company, Inc.	Camden, S. C., United States	Orlon
Acrylic	S	Tennessee Eastman Company	Kingsport, Tenn., United States	Verel
Acrylonitrile-styrene	M	Polymers, Inc.	Middlebury, Vt., United States	Algil
Polyethylene	M	Dawbarn Brothers, Inc.	Waynesboro, Va., United States	Dawbarn
Polyethylene	M	Firestone Plastics Company	Pottstown, Pa., United States	Firestone
Polyethylene	M	National Plastics Products Company	Odentown, Md., United States	Wynene
Polyethylene	M	Reeves Brothers, Inc.	Spartanburg, S. C., United States	Reevon
Polystyrene	M	Dawbarn Brothers, Inc.	Waynesboro, Va., United States	Dawbarn
Polystyrene	M	Polymers, Inc.	Middlebury, Vt., United States	Shalon
Polyvinyl-chloride	M	Polymers, Inc.	Middlebury, Vt., United States	"45"
Vinyon-type	S	American Viscose Corporation	Meadville, Pa., United States	Avisco Vinyon
Vinyl-acrylic	S	Carbide & Carbon Chemicals Company	South Charleston, W. Va., United States	Dynel
Vinylidene cyanide	S	B. F. Goodrich Chemical Company	Avon Lake, Ohio, United States	Darlan
Vinyl chloride-vinyl acetate	M	Polymers, Inc.	Middlebury, Vt., United States	Bistrand
Saran	M	Bolta Products—A Division of the General Tire & Rubber Company	Lawrence, Mass., United States	Boltaflex
Saran	C M	Dawbarn Brothers, Inc.	Waynesboro, Va., United States	Dawbarn
Saran	C S M	Firestone Plastics Company	Pottstown, Pa., United States	Velon
Saran	M	Lus-Trus Corporation	Ypsilanti, Mich., United States	Lus-Trus
Saran	M	National Plastics Products Company	Odentown, Md., United States	National
Saran	M	Oriented Plastics, Inc.	Pembroke, N. H., United States	Oriented
Saran	C S M	The Saran Yarns Company	Odentown, Md., United States	—
Saran	M	Southern Lus-Trus Corporation	Jacksonville, Fla., United States	Lus-Trus
Tetrafluoroethylene	C S	E. I. du Pont de Nemours & Company, Inc.	Richmond, Va., United States	Teflon

* C = continuous filament; M = monofilament; S = staple.

In addition to the development of new polymerizing procedures useful in work with the acrylic and vinyl fibers, certain new monomers have been polymerized and converted to fibers during the past few years. Included in this list are the vinylidene cyanide polymers developed by the Goodrich Tire and Rubber Company, Akron, Ohio, and the tetrafluoroethylene polymers developed by du Pont. Fibers spun from the former polymers possess a very soft and lofty hand, while the Teflon* fibers obtained from the latter have unexcelled thermal and chemical-resistant properties.

Dope preparation. In spinning many acrylic and vinyl polymers, solutions of the polymers in suitable solvents are commonly employed. Such solutions are known as dopes. While certain polymers are readily soluble in ordinary solvents, others can be dissolved only with great difficulty. In some cases, this lack of solubility has greatly retarded the development of specific types of fibers.

Acrylonitrile is readily converted to polyacrylonitrile (PAN) by relatively simple polymerizing procedures. This polymer has been known for a long time; from certain theoretical considerations, it was expected that the fibers obtained from it would possess attractive properties. However, since PAN does not melt, and since it is not soluble in ordinary solvents, no method was available to convert it into fibers.

Research work then was directed toward the development of new types of solvents. The first fibers were obtained by spinning PAN from solutions in sulfuric acid or from aqueous solutions of such inorganic salts as the metallic thiocyanates. Neither procedure offered a satisfactory solution to the problem, as the dopes obtained could not be handled by commercial procedures then available.

The discovery of dimethylformamide as a solvent for PAN was made almost simultaneously in the late 1930s by du Pont in the United States and by the I. G. Farbenindustrie, Essen, Germany. This compound proved to be the key that opened the door to the development of satisfactory acrylic fibers, as the dopes prepared from PAN in dimethylformamide were eminently suitable for the production of acrylic fibers. This forward step was followed by the discovery of several additional organic solvents, with the result that the fiber technologist now enjoys considerable latitude in choosing solvents for the production of PAN dopes for spinning.

Further developments in the field of metallic salt solutions as solvents for PAN have served to focus attention on this procedure for the manufacture of acrylonitrile fibers. The American Cyanamid Company, New York, N. Y., has found that aqueous solutions of certain metallic thiocyanates are desirable solvents for PAN if the resulting dopes are spun at low temperatures. Acrylic fibers possessing many desirable properties are obtained in this manner.

Of the three types of solvents originally investigated for the production of PAN dopes—mineral acids, aqueous inorganic salt solutions, and organic solvents—only the first is commercially unimportant at the present time.

In France, considerable work has been carried out on the development of carbon disulfide as a solvent for polyvinylchloride, either alone or in com-

* Registered du Pont de Nemours trade-mark.

bination with other solvents, such as acetone. Rhodiaceta's Rhovyl fiber is said to be spun in this manner.

Spinning. The wet- and dry-spinning procedures used in the manufacture of cellulosic fibers have been used, with certain modifications, for the production of vinyl and acrylic fibers. In the wet-spinning process, the dope is forced through spinnerets located under the surface of the spinning bath, the composition of which is designed to coagulate the fiber emerging from the spinneret. From a theoretical standpoint this is an interesting process, as the fiber consists of a continuous liquid medium containing the polymer as a discontinuous phase on the upstream side of the orifice of the spinneret. By contrast, on the downstream side, the polymer is the continuous medium and the solvent is the discontinuous phase. A complete reversal of phase, therefore, takes place almost instantaneously.

In the dry-spinning process, the dope is forced through spinnerets located at the upper end of a vertical chimney through which is passed a stream of heated gas or steam, usually in a countercurrent manner. During the passage of the fiber from the spinneret to the take-up device at the bottom of the tower, the heated gas or steam continually removes the solvent. The change in composition of the fiber from a continuous liquid phase containing dispersed polymer at the face of the spinneret to a continuous polymer phase containing dispersed solvent at the bottom of the chimney takes place more gradually than in the case of the wet-spinning process. This change leads to certain differences in the properties of fibers obtained from the respective processes. In essence, however, the procedures are closely related. Fibers spun by the wet process are surrounded by a liquid medium designed to remove the solvent present, while fibers spun by the dry process are surrounded by a gaseous medium for the same purpose.

In both the wet- and dry-spinning procedures the fibers obtained from the spinning bath or the spinning chimney are subjected to a number of additional processes, such as further washing to remove solvent, stretching to obtain the desired strength and elongation characteristics, heating to collapse the fiber, and drying. The exact procedures used and the order in which they are applied to the fiber can be varied at will to produce fibers that will meet the required specifications.

The melt-spinning process also has been used for the production of vinyl fibers. In general, the procedure used is similar to that employed in spinning nylon. The polymer is melted, pumped through fine orifices in a spinneret head, chilled by a stream of cold gas or air, and then stretched to impart the desired physical and chemical properties to the resulting fiber.

Since certain of these polymers do not melt, this process, as such, is not directly applicable to the production of acrylic fibers from PAN or to copolymers containing a high content of acrylonitrile. While they may be softened by the application of heat, they have a tendency to char and to form a gummy mass that cannot be handled in any known melt-spinning procedure. Although from time to time proposals have been made to spin plasticized PAN compositions, no commercial process has thus far resulted.

Recently, du Pont was confronted with the problem of spinning polytetrafluoroethylene, for which no suitable solvent was known and which was

insufficiently plasticized by heat for melt-spinning purposes. There was finally developed a procedure that involved the preparation of an emulsion of finely divided polymer, pumping it through a spinneret, and fusing the particles to form a continuous fiber by the application of heat.

This fourth spinning system, which is basically different from the classical wet-, dry-, and melt-spinning techniques, may be called emulsion-sintering spinning. This process provides a method for spinning a number of intractable polymers that cannot be handled by other procedures, thus making available a new series of high-softening, chemically resistant fibers that should find a number of applications in the industry. Du Pont's Teflon fiber already has met with wide public acceptance.

After spinning, continuous-filament acrylic and vinyl yarns usually are stretched to develop desirable physical properties and then treated with a finish to lubricate the fibers and control their electrostatic characteristics. The fibers are then dried, packaged, and distributed to the trade.

In the spinning of staple fiber, the yarns obtained from the primary spinning operations are stretched, run through a finish bath, dried, and crimped. A great deal of experimentation has been performed on this phase of the operation, as staple fibers must be crimped in a definite manner in order to obtain a staple that can be processed on standard textile equipment. Mechanical crimping devices are generally used for this purpose, the exact design of the crimper depending, among other things, upon the characteristics of the fiber being processed.

The chemical crimping of fibers has received some attention, but no completely satisfactory process has been developed to date.

In the manufacture of staple, several yarns generally are combined to form a tow prior to the cutting operation. This is also a critical procedure, as the presence of an unduly large proportion of either short or long fibers in the staple can interfere seriously with the subsequent production of spun yarns.

Fiber processing. A number of procedures designed to change the physical and chemical characteristics of acrylic and vinyl fibers are being investigated. These include the application of heat, the use of certain chemicals, and mechanical treating processes.

A comparatively new development is the exposure of fibers to certain radiations. Such treatment usually results in cross-linking the polymer chains. Under carefully controlled conditions, vinyl fibers such as those obtained from polyethylene develop improved thermal resistance and strength, with a corresponding reduction in elasticity and solubility. More prolonged exposure to radiation results in the conversion of the fiber to a completely insoluble and infusible form. It is evident that this procedure offers the possibility of making an entirely new series of fiber types having many applications, particularly in the industrial field.

Procedures for altering the surface characteristics of continuous-filament yarns also are being investigated. In the Taslan* process developed by du Pont, a multifilament yarn is passed through a fine orifice accompanied by a stream of air moving at high velocity. This causes the formation of

* Registered du Pont de Nemours trade-mark.

tiny loops at irregular intervals along the yarn, thus breaking up its smooth surface and providing a textured effect. When converted to fabrics, a hand and touch similar to those of a spun-yarn fabric are obtained.

Bulk yarns also are being produced from a number of acrylic fibers; at least three general procedures are currently employed for this purpose:

(1) The tow is stretched at elevated temperatures and converted to staple, after which the staple is blended with normal staple and spun into yarn.

(2) The tow is heated, stretched, and broken on a Turbo Stapler* to form a sliver. A portion of the sliver is relaxed in the presence of steam at elevated pressures, then mixed with unrelaxed sliver, and converted to yarn.

(3) Tow is stretched at elevated temperatures (hibulked), combined with normal tow, cut to sliver on a Pacific Converter,† and spun to form yarn.

When the yarns are converted to knit or woven fabrics and then steamed or immersed in hot water, as occurs in dyeing operations, the stretched fibers relax and pull the unrelaxed fibers into disordered clumps. This increases the apparent bulk of the yarn and gives a lofty hand to the fabric. Bulk yarns are generally used in the manufacture of sweaters, as well as a variety of other garments made of acrylic fiber.

In this connection, also, it is well to emphasize that certain vinyl and acrylic fibers possess the ability to shrink substantially at elevated temperatures. A practical application of this property is the use of such fibers as backing for pile fabrics. A denser pile is obtained and, upon shrinking, the pile fibers are firmly locked in the backing.

General considerations. The chemical and physical nature of the polymer to a very substantial extent determines the degree of crystallinity of the resulting fiber, as well as its thermal, mechanical, and water-absorbing properties. Thus, for example, no simple spinning techniques will make normal polystyrene fibers crystalline or strong, or give them the ability to withstand high temperatures or to absorb water. The inherent molecular characteristics of PAN, on the other hand, produce fibers having all of these characteristics, with the exception of water absorbency. To achieve the latter, acrylonitrile must be copolymerized with an appropriate monomer or the PAN blended with a polymer possessing water-absorbing properties.

The spinner is charged with the responsibility of converting the polymer into fibers having the desired characteristics. To a very considerable extent, certain properties may be enhanced by the selection of the proper spinning procedure, but this must be done in such a way as to maintain a good balance with respect to the other characteristics of the fiber. A highly stretched fiber, for example, will have good tenacity, but this is achieved at the expense of increased brittleness and reduced moisture regain.

Important physical characteristics of fibers include tenacity and elongation, as measured both in the dry and in the wet state, stiffness, toughness, elasticity, sorption, heat shrinkage, color, and electrical properties.

Important chemical properties of fibers, qualities that may be colloidal in nature, include dyeability, launderability, and resistance to solvents, alkalis, and acids.

* Manufactured by the Turbo Machine Company, Lansdale, Pa.

† Manufactured by Warner & Swasey Co., Cleveland, Ohio.

Important properties of textiles are the degree of uniformity of the fiber with respect to denier and length of staple, finish, crimp, shape of cross section, and the surface characteristics of the fiber. Obviously, it is necessary that the fiber possess all of the characteristics, some of which are intangible in nature, that will permit it to be spun into yarns, converted to fabrics by standard weaving or knitting procedures, and dyed and finished by conventional methods and with the use of conventional equipment.

Finally, the fabric must lend itself to normal cutting and sewing operations, and the finished garment must have a pleasing hand and drape.

Polyvinylchloride fibers, either the afterchlorinated types developed in Germany or the vinyl chloride-vinyl acetate copolymer types developed in this country, were the first vinyl fibers to meet commercial acceptance. Polyvinylidene chloride fibers, vinyl chloride-acrylonitrile copolymer fibers, and formaldehyde-treated polyvinylalcohol fibers came next. Polyethylene monofilaments and polyvinylchloride fibers followed. The acrylic fibers, either spun from PAN or from acrylonitrile copolymers, appeared on the market after World War II and have assumed a position of commanding importance in the industry. Polyvinylidene cyanide fibers and polytetrafluoroethylene fibers came later, to be followed by graft-polymerized acrylonitrile fibers and the acrylic alloy fibers.

While several vinyl fibers are of importance commercially, the acrylic fibers have met with the greatest degree of public acceptance. This is due, to a certain extent, to their lofty, wool-like hand, their good processing characteristics, and the ease with which they can be dyed and finished by conventional procedures. In addition, they have good wrinkle-resisting and crease-retaining properties; they resist the deteriorating action of chemicals, sunlight, and most microorganisms; they resist attacks by moths and insects; and they blend well with other natural and synthetic fibers. Their future possibilities are suggested by the fact that the President's Materials Policy Commission has estimated that 1,200,000,000 pounds of acrylic fibers will be produced and sold annually by 1975.⁹

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MOISTURE, TEMPERATURE, AND FIBER PERFORMANCE

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Introduction

To meet the many requirements of the textile industry, the garment trade, and the consumer, fibers must have a delicate balance of stable and unstable characteristics. While they must possess and retain minimum levels of such characteristics as strength, stiffness, and appearance, fabrics must at the same time have a certain instability or workability so that they may be dyed, chemically treated, shrunk, heat set, embossed, pleated, and pressed. Without this limited instability we could neither effect the processes of dyeing and finishing nor employ the high bulk and stretch yarns that are reported elsewhere in these pages. The two prime regulators for this workability or controllable instability are moisture and temperature. However, these factors, when not suitably controlled, can be responsible for major problems in processing and use. A few examples are those posed by static and mill wrinkles in processing, by the wrinkling of clothing in wear, and by the holes resulting from tobacco embers or hot irons.

The recognized importance of moisture as a variable affecting fiber performance is exemplified by the extensive use of the terms "hydrophilic" and "hydrophobic" as a primary basis for classifying fibers. In one sense this classification is unfortunate. With "hydrophobic" fibers, moisture plays a minor role in comparison with temperature. For these fibers, the use of the term "thermophilic" would probably be much more descriptive. This term is preferred over "thermoplastic" since, where fibers are concerned, many thermal responses, affecting such factors as elasticity, stiffness, and crystallization, involve no significant intermolecular displacement or deformation.

Accordingly, it seems desirable to begin the present section of this monograph on fiber applications with a brief discussion of some of the similarities of moisture and temperature as regulators of the performance of hydrophilic and thermophilic fibers.

Discussion

For purposes of our discussion, let us first review a few simple aspects of fiber structure. A fiber is composed of thousands of long, thin, flexible, chainlike molecules arranged generally lengthwise in the fiber. The molecule is very strong along the chain. In wool, the long, thin chains are held together by periodic strong covalent bonds that act as cross links and convert the molecular assembly into a stable three-dimensional network system. With most other fibers, the assembly is held together by periodic strong local interaction of attractive forces where adjacent molecular segments happen to fit together closely with a high degree of three-dimensional symmetry. FIGURE 1 is a simplified diagrammatic picture of such a structure.



FIGURE 1. The structure of a fiber: (C) crystalline areas; (A) amorphous areas.

TABLE 1
THE CONTRIBUTIONS OF DIFFERENT AREAS OF A FIBER TO ITS OVER-ALL CHARACTERISTICS

Crystalline areas	Amorphous areas
Stiffness	- Plasticity
Moisture stability	Absorbency
Temperature stability	Formability
Dimensional stability	Dyeability
Network strength	Toughness

In the well-ordered crystalline regions (C) the segments are very close together and have a high degree of order. In the more poorly ordered amorphous regions (A), the molecular segments are arranged in a relatively random fashion and have a low degree of interaction. The close-packed crystalline areas are resistant to the penetration of water or other chemicals and are quite stable to temperature. The amorphous areas, with their lower degree of order, are readily permeable by moisture and chemicals, and they are more sensitive to temperature. Relative contributions of the crystalline and amorphous areas are summarized in TABLE 1. As can be seen, the crystalline areas tie the network system together and make a major contribution to the ultimate stability of the fiber. Most of the factors of workability reside in the amorphous areas.

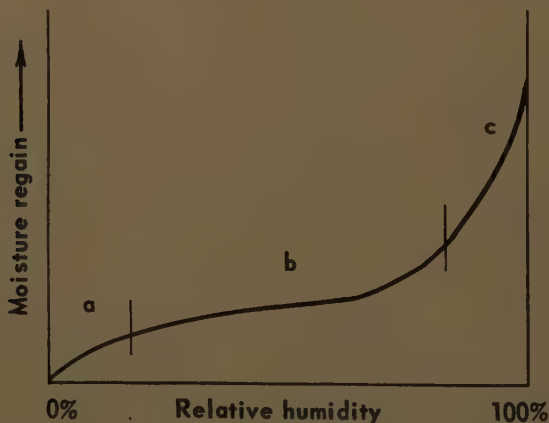


FIGURE 2. Moisture regain *versus* humidity.

The extent to which fibers absorb moisture depends on the presence of polar groups and the availability of these groups in the amorphous areas. The principal polar, water-binding groups in fibers include hydroxyl, amino, carboxyl, imido, and carbonyl groups.

As a preliminary basis for discussing the relationship of moisture to fiber properties, let us briefly consider the representative moisture-regain *versus* humidity curve (FIGURE 2) for a hydrophilic fiber. It is readily apparent

that the curve is S-shaped. Absorption increases rapidly for the first 10 per cent of relative humidity (RH), more slowly from 10 to about 80 per cent RH, and then very rapidly from 80 to 100 per cent RH. In the region up to 10 per cent RH, *a*, moisture is absorbed by uncoordinated, freely available polar groups in the amorphous areas. The 10 to 80 per cent RH moisture represents a slower spreading apart of the remaining polar groups in the amorphous areas and a saturation of the molecular binding potential of all available polar groups. This region, *b*, involving the solution and masking of partly coordinated polar groups, exerts its greatest effect in reducing the rigidity of the fiber. The combined 0 to 80 per cent RH moisture thus consists primarily of water molecules directly bound to polar groups with varying degrees of availability. The sharp increase of absorption in the 80 to 100 per cent RH region, *c*, probably involves multilayer condensation, especially between saturated polar sites in the smaller capillary pores of the fiber. This unbound moisture is held only loosely by the fiber.

In discussing the thermal characteristics of fibers, it is desirable to start with a definition of two convenient yardsticks. These are defined in TABLE 2 and are descriptive of major changes in state brought about in fibers by changes in temperature. These yardsticks, conveniently known as transition temperatures, are: the so-called first-order transition temperature at which the crystalline areas melt and the fiber becomes sticky and loses its shape and strength; the second-order transition temperature, which is lower than that of the first order, is the temperature at which the amorphous areas begin to pass from a solid to a liquid state, and the fiber becomes more flexible and tough. For any given fiber these temperatures vary somewhat, depending on the particular method of testing used and the rate at which they are determined. For purposes of discussion I have preferred to think of these temperatures in terms of their effect on the useful properties of fibers, and I have designated representative transition temperatures as *T_{cryst.}* and *T_{amor.}* Experimental curves for stiffness* versus temperature¹ are shown in FIGURE 3 as an example of the significance of these transition temperatures. If we follow along the curve for cellulose acetate fiber we find that it maintains its stiffness to a fairly high temperature in the neighborhood of 160° C., and that it then drops very rapidly until it retains no significant stiffness when it reaches a temperature of 200° C. In the case of normal cellulose acetate, which is mostly amorphous in character, this rapid softening and melting essentially parallels the melting of amorphous areas. In the second curve, Dacron, which is relatively crystalline, shows a partial drop in stiffness that begins at a temperature of about 80° C.

TABLE 2
TRANSITION TEMPERATURES

T_{cryst.} (first-order transition temperature) = temperature at which the crystalline areas melt. At this point the fiber becomes sticky and loses its shape and strength.

T_{amor.} (second-order transition temperature) = temperature at which amorphous areas begin to pass from a solid to a liquid state. At this point the fiber becomes flexible and tough.

* The formula for the calculation of the stiffness of a fiber is: grams/denier/1 per cent stretch $\times 100$.

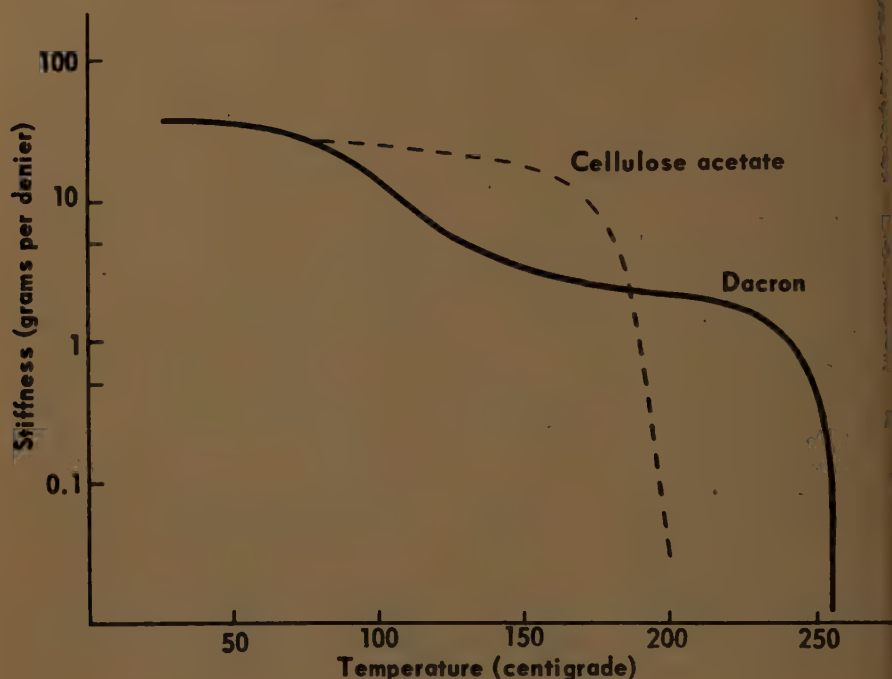


FIGURE 3. Stiffness versus temperature.

and then maintains a portion of its stiffness until a temperature in the vicinity of 250° C. is reached. At this point there is a very rapid final drop in stiffness. The transition temperature at about 80° C. represents $T_{amor.}$ melting or softening in the amorphous areas. However, since a considerable number of crystalline areas hold the network structure together, the fiber maintains itself until it finally reaches its $T_{cryst.}$ temperature, at which point the crystallites begin to melt, and the fiber becomes sticky and loses its strength.

In TABLE 3 are listed a number of fiber characteristics that can be used in making a preliminary comparison of the hydrophilic and thermophilic nature of fibers. Effective crystallinity is used as a rough measure of the stability of the network that holds the molecular assembly together until the crystallites are destroyed. Important factors are the molecular weight of the polymer and the number, size, distribution, and perfection of the crystallites. Regain at 70° F. and 65 per cent RH gives a fair relative measure of the number and affinity of the polar groups available to moisture in the amorphous areas. Thus cotton, which has substantially higher crystallinity than rayon, is less readily accessible to moisture and has a lower regain. The values for swelling are a measure of the extent to which the network system can be swollen without damage. The values for $T_{amor.}$ and $T_{cryst.}$ are representative values that indicate the temperatures at which the amorphous and crystalline areas become affected. It can readily

be seen that the more hydrophilic fibers all have high transition temperatures. The newer thermophilic fibers have lower transition temperatures in the range in which they significantly affect fiber performance. Fibers such as acetate, Orlon, and nylon are intermediate cases and show some sensitivity to both moisture and temperature.

The effect of various hydrophilic and thermophilic states on fiber properties is illustrated in TABLE 4. For condition *a*, hydrophilic fibers in a dry, low regain state and thermophilic fibers at temperatures below $T_{amor.}$ are stiff, resilient, and strong. For condition *b*, where the amorphous areas are plasticized or softened, normal regain or temperatures in the range of $T_{amor.}$ contribute increased elongation and toughness. In condition *c*, where the fiber is wet or above the $T_{amor.}$ range, the amorphous areas make little contribution, and the fiber is soft, resilient, and weak. Finally, for condition *d*, a fiber in a highly swollen state or at the $T_{cryst.}$ temperature is sticky and has no strength.

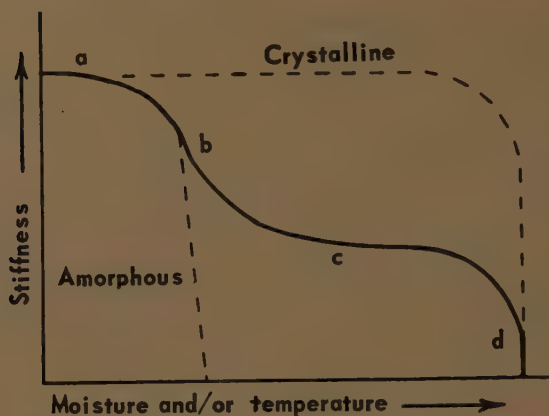
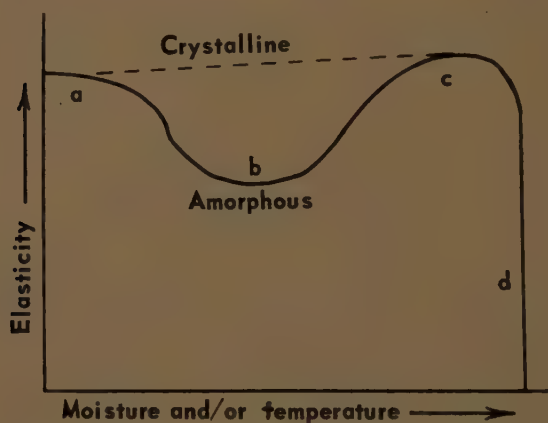
A generalized picture of the effect of moisture and/or temperature on the stiffness of a fiber is shown in FIGURE 4. The solid curve represents the relative effects of moisture and/or temperature on the stiffness of a normal fiber containing a combination of amorphous and crystalline regions. The

TABLE 3
HYDROPHILIC-THERMOPHILIC FIBER CHARACTERISTICS

Fiber	Effective crystallinity	Regain (%)	Swelling (%)	$T_{amor.}$ (°C)	$T_{cryst.}$ (°C)
Rayon.....	+	14	65	—	Decomp.
Wool.....		16	26	—	Decomp.
Cotton.....	++	8	21	—	Decomp.
Silk.....	++	11	19	—	Decomp.
Acetate(di).....		6	8	160	200
Orlon.....	+	2	5	80	200
Nylon.....	++	3	3	50	225
Dacron.....	++	0.4	1	80	225
Dynel.....	+	0.5	—	80	170
Saran.....	++	—	—	0	150
Polyethylene.....	++	—	—	-25	110

TABLE 4
COMPARATIVE HYDROPHILIC-THERMOPHILIC FIBER BEHAVIOR

Condition	Hydrophilic state	Thermophilic state	Properties
<i>a</i>	Dry	Below $T_{amor.}$	Stiff, strong, resilient
<i>b</i>	Normal regain	$T_{amor.}$ range	Plastic, tough
<i>c</i>	Wet	Above $T_{amor.}$ range	Soft, weak, resilient
<i>d</i>	Swollen	$T_{cryst.}$	Sticky, no strength

FIGURE 4. Moisture and/or temperature *versus* stiffness.FIGURE 5. Moisture and/or temperature *versus* elasticity.

conditions previously described are designated by those portions of the curve marked *a*, *b*, *c*, and *d*. When it has a completely amorphous structure, a fiber rapidly loses all of its stiffness in going from condition *a* at low regain or below $T_{amor.}$ to condition *b*. If it is completely crystalline, moisture and temperature have relatively little effect until condition *d* is reached. The fiber is then highly swollen or at its $T_{cryst.}$ temperature. Since it contains both amorphous and crystalline areas, an individual fiber shows a reduction of stiffness in the amorphous areas as moisture is absorbed or as it reaches the $T_{amor.}$ temperature range, after which the crystallites hold the fiber together until these are destroyed by a swelling agent or by increased temperature.

The next generalized picture is that of the effect of moisture and/or temperature on the elasticity of the fiber. In FIGURE 5, the solid line represents a normal fiber that contains amorphous regions. The dashed line shows the hypothetical behavior of a completely crystalline fiber. In such a fiber, under condition *a*, there is little displacement of molecular segments in the

amorphous region, and elasticity is high. Then, in condition *b*, where the amorphous molecular segments are somewhat lubricated or plasticized, there is some displacement of segments and groups of segments, and these are then hindered in returning to their original positions by the presence of other nearby attractive forces that are not yet completely masked or free. In condition *c*, where the amorphous molecular segments are completely masked and have a high degree of freedom, the fiber shows improved elasticity. An example of the difference in behavior of fibers in the *b* and *c* conditions is that in which a fiber such as viscose is stretched under conditions of normal regain and shows only partial elastic recovery even after an extended period of time. However, this same stretched fiber will soon shrink back to its original length when wet. The added moisture increases the freedom of the molecular segments and permits them to return to their original positions. Under condition *d*, swelling or increased temperature bring the fiber into a relatively dissolved or liquid state, and elasticity drops rapidly.

What can be said about the general effect of moisture and temperature upon the stress-and-strain properties of fibers? FIGURE 6 shows idealized curves for fibers in conditions *a*, *b*, *c*, and *d*. Condition *a* is characterized by high strength; *b*, by higher elongation and increased plasticity and toughness; *c*, by low initial stiffness and strength; and *d*, by lack of strength.

Recent studies further emphasize the importance of transition temperatures in relation to fiber and fabric performance. Brown¹ has related the temperature range between $T_{amor.}$ and $T_{cryst.}$ to the minimum and maximum ironing temperatures for thermophilic fibers. He further postulated that, in ironing, a fiber must be heated until its stiffness falls to 3 gm./denier before wrinkles can be removed and must not be heated above a temperature at which this stiffness is below 0.1 gm./denier or damage will result. In an excellent study² illustrated in FIGURE 7, scientists of I. E. du Pont de Nemours, Inc., Wilmington, Del., determined that wrinkles simulating those of wear and wrinkles formed during laundering could be removed, to a

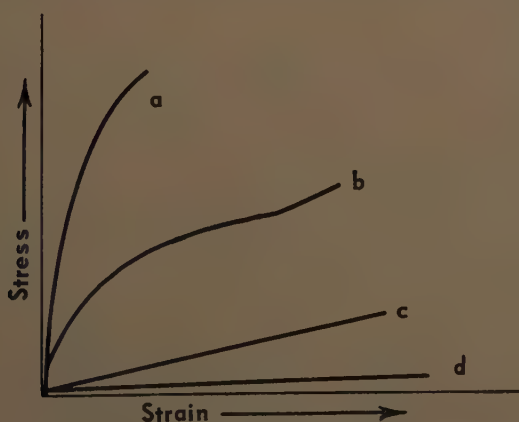


FIGURE 6. Moisture and/or temperature effects on stress-strain properties.

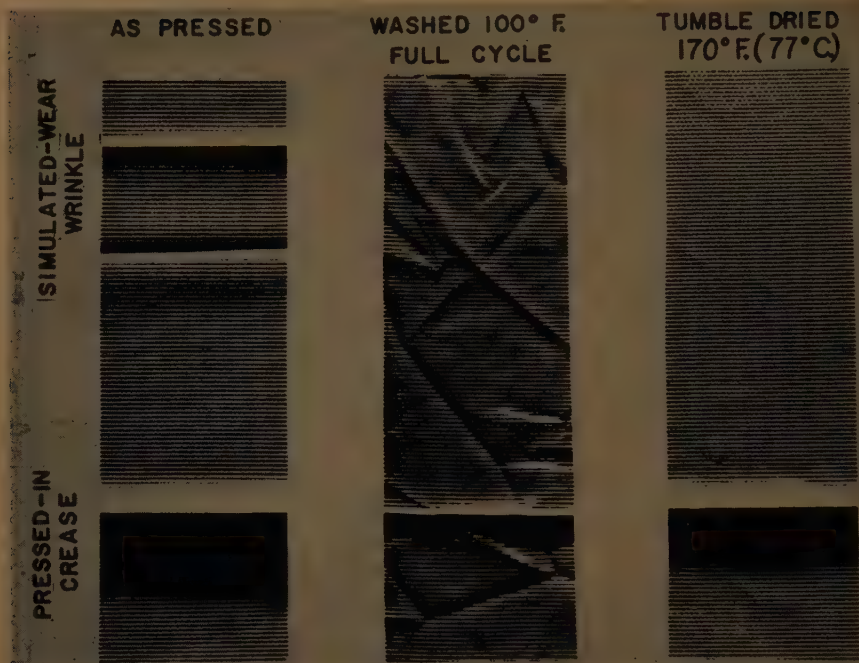


FIGURE 7. The results of laundering a sample of cord suiting (85 per cent Dacron and 15 per cent nylon).

considerable extent, by tumble drying at a temperature of about 170° F. (77° C.). This heat is in the vicinity of the second-order transition temperature for the fibers tested. The report interprets their findings as follows:

"It thus appears that it is necessary to raise the temperature of these fibers to the vicinity of their second-order transition temperature in order to obtain effective wrinkle removal. For at the second-order transition temperature the mobility of the molecules is appreciably increased, thus facilitating the return of the polymeric molecules to their equilibrium position from which they were forced when the fiber was deformed in wrinkling. Since no significant wrinkling is introduced with any of these fibers until the temperature exceeds 180° F., it appears that the optimum temperature for tumble drying is $170^{\circ} \pm 10^{\circ}$ F."

Much additional work remains to be done before the simplified over-all picture that has been presented can be spelled out in greater detail. Because the newer man-made fibers are predominantly thermophilic in nature, most current studies deal primarily with their thermal behavior. In order better to compare and understand the old and the new fibers, it may be worth while now to re-examine their hydrophilic characteristics. In performing tests for these characteristics, it appears that tests of stiffness may be particularly suitable because of the magnitude of the changes involved and the possibility of obtaining many results with a single sample.

Conclusions

Textile fibers must combine stability with ease of manipulation in processing and use.

The stability of a fiber is primarily the function of highly ordered crystalline areas that hold the molecular network together. These crystallites are relatively insensitive to moisture and temperature.

The ease with which a fiber can be manipulated in processing and use is primarily a function of poorly organized amorphous areas and is governed by their availability and their sensitivity to moisture and temperature.

Because of the strong influence of moisture and temperature on their behavior, fibers should be classified by hydrophilic and thermophilic attributes.

A preliminary comparison can now be made of representative hydrophilic and thermophilic fiber characteristics.

General similarities in the effects of moisture and temperature on fiber properties can be related in terms of fiber structure and molecular mechanisms.

Finally, to judge from the data presented here, it appears likely that further studies of similarities in the moisture and temperature dependence of fibers may lead to new yardsticks for use in the development of improved fibers and fabrics.

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PROBLEMS AND ADVANCES IN THE DYEING AND FINISHING OF MAN-MADE FIBERS

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In any discussion of dyeing and finishing man-made fibers, we are faced not only with developments concerning the older fibers, but also with those of fibers now being introduced. Present activity in newer fibers, especially those derived from acrylonitrile, is considerable; aside from Orlon* acrylic fiber, Dynel,† and Acrilan,* the 3 older types, there are fibers in various stages of development offered under the trade-mark Verel,* Creslan,* Zefran,* and Darlan.* Such activity often leads to confusion as to methods of processing, dyeing, and finishing, since these fibers differ in their chemical make-up and physical behavior. The problem of dyeing blends of newer fibers with older fibers is especially challenging. The dyers and finishers thus are called upon to process fibers and fabrics that were unimagined a few years ago. A dyehouse formerly specialized in wool or cotton or such synthetic fibers as rayon, acetate, and nylon. This picture is changing, and an integrated setup involving all fibers is now more common. In all new developments, cooperation between chemists and engineers applying these new processes is necessary; promising laboratory discoveries become valuable only when reduced to commercial practice.

Nylon

In the United States, 66 nylon, made from polyhexamethylene adipamide, has become established for filament or staple uses. Lately, 6 nylon, made by several concerns, has become available. The 6 nylon, being made of polycaproamide, differs chemically, has a lower softening point, and thus must be handled differently from 66 nylon; it dyes faster than 66 nylon and possesses a lower degree of fastness to washing. Lightfastness of the two fibers is equivalent.

Techniques for the simultaneous dyeing and twist setting of nylon yarn and rawstock, using the durable neutral-dyeing metalized dyes, have been perfected and are being used commercially.^{1a-1c} Moreover, dyeing nylon fabrics in the piece in the Burlington Hy-Press machine, and using the same types of dyes, is practicable.² In these cases, the use of specific nonionic auxiliaries and alkyl alcohol sulfates assists in producing level dyeings.

* Registered trade-marks: Orlon, E. I. du Pont de Nemours & Company, Inc., Wilmington, Del.; Acrilan, The Chemstrand Corporation, Decatur, Ala.; Verel, Tennessee Eastman Company, Kingsport, Tenn.; Creslan, American Cyanamid Company, New York, N. Y.; Zefran, Dow Chemical Company, Midland, Mich.; and Darlan, B. F. Goodrich Chemicals Company, Cleveland, Ohio.

† Dynel is a registered trade-mark of Carbide and Carbon Chemicals Co., New York, N. Y.

The importance of the role of chemicals in effecting dye transfer or controlling the rate of dyeing cannot be overemphasized in working with the newer fibers.

In dealing with blends of nylon and wool, colorless anionic organic compounds are used with acid dyes to decrease the rate of dyeing³ on nylon; the colorless anions compete with the dye for the amino dye sites on the nylon. The selection of color and the time of dyeing are very important, because both nylon and wool compete for the same dye.

In the dyeing of nylon filament with acid dyes, the use of alcohol sulfates at 212° F. and above has considerable value. Here again, the quicker-exhausting alcohol sulfate either (1) cuts down the rate of strike of the acid dye for the more rapidly dyeing portions of the nylon, or (2) causes migration of dye at temperatures above 212° F. The use of phenol in the dye bath (Cheney process) to give dyeings with levelness at the boil has been disclosed.⁴ The toxic nature and disposal problems of phenol limit its general use.* Very recently, the Chemnyle process of applying acid and direct dyes was announced; it is reported that the use of an experimental auxiliary assists in producing more level dyeings.⁵

Considerable interest in bulked, textured, and stretch nylon is evident. Again, the same principles for level dyeing must be followed.

The importance of proper preparation of nylon fabric or yarn cannot be overemphasized. Treatment with anionic surface-acting agents in acidic media under certain conditions of time and temperature can cause severe degradation by hydrolysis of nylon.⁶ Surface hydrolysis will lead to additional amino groups in the polymer, leading to greater dyeability in such areas by acid dyes.

Careful physical handling is required, since more highly oriented nylon will dye at a slower rate and thus lead to unlevel dyeings.

Two new commercial machines for dyeing full-fashioned nylon hosiery, the Proctor and Schwartz Electroset^{7a, 7b} and the Turbo Dyeotherm,^{8a, 8b} have been announced. Scouring, dyeing, and finishing are done on forms mounted in a pressure vessel. Dyeing takes place at temperatures of approximately 235° F.

Orlon

Orlon can be dyed with many classes of dyes. With disperse dyes, only pale shades can be obtained, but these have good fastness properties. Orlon can also be dyed by use of the cuprous ion with anionic dyes.^{9a-9c} By far the most important are the cationic dyes.

The revival of the cationic dyes for textiles has paralleled the phenomenal growth of the production and use of Orlon. New dyes have been developed with the lightfastness necessary for use in apparel. Their wetfastness is excellent. These dyes exhibit better lightfastness on Orlon than on any other nitrogen-containing synthetic fiber. Cationics exhibit such brightness that, in the trade, the dulling of shades is frequently practiced.

The dyeing process involves site mechanism.¹⁰ The dyes form salts with acid sites in the fiber. Levelness can be achieved in the light and medium

shades by the use of suitable alkyl ammonium retarding agents that have a greater rate of absorption than the dyes. The use of sodium sulfate¹¹ and of such anionic agents as organic sulfonates¹² in the dye bath has also been found to effect leveling.

The dyeing of blends of Orlon and wool, cellulosic fibers, or nylon is rather simple, since the latter fibers have little affinity for cationic dyes, and the anionic dyes used for the companion fiber have little or no affinity for Orlon.¹³ Nonionic agents greatly minimize the staining of the older basic dyes. In dyeing blends of Orlon and Dacron,* cationic dyes are used for the Orlon and the nonionic disperse dyes for the Dacron in the presence of a suitable carrier.

Skein dyeing of high-bulk yarns, using modified skein-dyeing machines, enjoys successful commercial exploitation.^{14a, 14b} There is considerable interest in tow dyeing for high-bulk fiber; a great deal of yarn is now dyed in batch equipment. A continuous process, using cationic dyes in the presence of ethylene carbonate, and using padding followed by steaming and scouring^{14, 15} appears attractive on a laboratory scale for light to medium-heavy shades. The penetration of the sweater field by Orlon has been extensive. The furlike fleece fabrics made with Orlon are increasing in importance.

One of the problems in the dyeing of Orlon has been the inability to produce heavy shades with cationic dyes in reasonable periods of time. Du Pont has mill trials under way with an Orlon type 42 having a faster dyeing rate. This problem should accordingly be nearing solution.

Plans for further expansion in the manufacture of Orlon acrylic staple have been disclosed by du Pont.

Acrilan

This acrylonitrile-based polymeric fiber can be dyed with many types of dyes.^{16a, 16b} The fiber has a basic modifier, being dyeable with anionic dyes at a low pH. The lightfastness of dyes on this fiber is lower than on wool, but washingfastness is superior. Since wool and Acrilan are dyed with the same acid dyes, an auxiliary must be used to regulate distribution of dye between the two fibers. At equilibrium, the Acrilan without auxiliaries will absorb all the dye. In dyeing mixed shades, careful color selection is necessary, since rates of dyeing must be comparable to get union shades.

The cationic and disperse dyes also dye Acrilan. The brightness of cationic dyes again is an asset for use in knitwear.

The dark shades can be made with the anionic chrome dyes; chroming is more difficult on Acrilan than on wool. Chrome colors have good wet-fastness properties.

In dyeing blends of Acrilan and cellulose, disperse dyes are used on the Acrilan, and the cellulosic portion is dyed conventionally.

Dynel

Dynel, a 40/60 copolymer of acrylonitrile and vinyl chloride, can be dyed with disperse, cationic, and selected anionic acid dyes, the latter gen-

* Dacron is a registered trade-mark of E. I. du Pont de Nemours & Company, Inc.

erally with the aid of the cuprous ion.^{17a-17d} Procedures for the use of this process have been developed, and they are now being practiced commercially.

New Synthetic Nitrogenous Fibers

Verel, developed by Tennessee Eastman, is dyeable with disperse, neutral-dyeing metalized, and cationic dyes.¹⁸ This fiber is in the development stage. Eastman claims that this fiber is suitable for many end uses.

Creslan, produced by American Cyanamid, is in the same position, being in the pilot-plant stage, although it has been announced that a plant will be built at Pensacola, Fla., to be ready by 1958. This fiber may be dyed with disperse, acid, chrome, and cationic dyes.¹⁹

Zefran, a nitrile alloy produced by Dow Chemical, can be dyed with direct, vat, sulfur, neutral-dyeing metalized acid, cationic, and disperse dyes;²⁰ dyeability with disperse dyes is good, but wetfastness with this fiber is of low order when compared with the other acrylic fibers. Zefran differs from the other new fibers in that it is dyeable with the more hydrophilic dyes such as those used for cotton and rayon. Union, tone-on-tone, cross-dye effects are obtainable in blends with either wool or cellulosic fibers. Dow will construct a plant at Lee Hall, Va., to be completed in about 16 months.

Darlan, a product of B. F. Goodrich Chemicals, is a copolymer of vinylidene nitrile and vinyl acetate²¹ and is undergoing pilot-plant development. Darlan is being used initially in furlike fabrics. It is dyeable with disperse, cationic, and acid dyes, the latter using cuprous ion. No decision to make this fiber commercially has been announced.

The dyeing of blends of many of these fibers remains to be perfected. Much will depend on the dyeability of such blends with various classes of dyes under practical conditions.

Dacron Polyester Fiber

Dacron has been established as a synthetic fiber for many end uses. It is dyeable only with disperse dyes at atmospheric pressure with dyeing assistants, called carriers, which increase the rate of dyeing, or at elevated temperatures up to 260° F.²² Special disperse dyes (Latyl*), introduced in 1953 by du Pont, and older disperse dyes furnish a complete range of shades. Excellent lightfastness is obtainable, while the wetfastness properties are good to excellent. In deep navy and black shades, solvent bleeding and sublimation remain as problems, generally due to the properties of the nonionic disperse dyes that possess vapor pressures sufficient to cause sublimation of dye on heating or show slight bleeding with chloroethylene dry cleaning solvents. Blacks are made by using diazotizable azo dyes and 2-hydroxy-3-naphtharylides that are exhausted on the fiber at 250° F.; reaction with nitrous acid effects simultaneous diazotization and coupling. Appropriate scouring follows.

Pressure dyeing at temperatures above 212° F. has been well accepted

* Registered trade-mark of E. I. du Pont de Nemours & Company, Inc., Wilmington, Del.

for rawstock, yarn, and fabric. In piece dyeing, the Burlington beam-dyeing machine is widely employed. The Barotor dyeing machine also produces excellent results.

Many types of carriers,^{23a-23c} including the chlorobenzenes, *o*-phenylphenol, methyl salicylate, and many proprietary carriers are available in dispersible or emulsifiable form. Since many are oils at dyeing temperatures, much has been done to perfect techniques to prevent the carrier from breaking out of dispersion and making oil spots. Latyl Carrier A is a product that does not melt at the boiling point. The carrier *o*-phenylphenol should be sublimed out after the dyeing process to achieve maximum lightfastness. Many dyehouses have been equipped with proper ventilation facilities to permit use of the toxic chlorobenzenes for dyeing light to medium-heavy shades.

The mechanism of dyeing Dacron was found by Schuler and Remington²⁴ to be one of solution, the disperse dye diffusing into the fiber from aqueous solution. At equilibrium, a linear plot is found between concentrations of dye in the fiber and dye dissolved in the bath.

The English and continental workers have more recently substantiated with Terylene the American developments on Dacron. Diphenyl has found some use as a carrier in England.²⁵ A recent disclosure of the use of low-boiling alkyl chloride in a Vapacol Process for dyeing represents a novel approach to dyeing polyester fibers.²⁶ A dyeing process involving high boiling solvents for dyeing polyester fibers at high temperatures has been described recently.²⁷

The dyeing of blends of Dacron and wool, the Dacron being dyed with disperse dye and the wool with acid colors, is well established. Dacron-wool blends have captured much of the men's lightweight summer suiting market.

Blends of Dacron and cotton are exceedingly popular. The Thermosol process for dyeing this blend is in the development stage.²⁸ The disperse dye is padded, the fiber is dried, and the disperse dye is dissolved in the Dacron fiber by a heat treatment for 1 min. at about 400° F. In the blend, the disperse dye for Dacron and vat dye for cotton are padded and dried, heat treated, padded with sodium hydroxide and sodium hydrosulfite, steamed to fix the vat dye on cotton, oxidized, and scoured. The disperse dye does not dye the cotton, and the vat dyes (structurally large nonionic disperse dyes as padded) generally do not dye Dacron, so that union dyeing is simplified. The efficiency of the use of disperse dye in this blend is excellent.²⁹ These dyeings display excellent fastness properties for wash-and-wear use. It is to be noted that the first public disclosure of the Thermosol process was made in 1949 and, although the process had previous mill trials, it is just now becoming important commercially.

Interest in blends of Dacron with nylon, Orlon, and rayon continues, and technology to handle them satisfactorily is available.

There is need for the following in the dyeing of Dacron: (1) a cheap carrier that has no effect on fastness properties and that will not be an oil at the boil (212° F.); (2) cheap blue dyes with good lightfastness; and (3) economy in time of dyeing.

Triacetate Fiber

Considerable interest has been evinced in Arnel,* a cellulose triacetate fiber introduced in 1954. Arnel has affinity only for disperse dyes, as does secondary acetate; however, it is more difficult to dye, requiring carriers (usually alkyl phosphate derivatives), longer dyeing times, or higher temperatures.³⁰ Thermosol dyeing is effective. The gas-fume deficiency of secondary acetate is present, and dyes fast to gas fumes are preferred over the use of gas-fume inhibitors. Generally, a light-fast dye is also fast to gas fumes. The availability of dyes fast to gas fumes for secondary acetate and Dacron has aided in the development of dyeing processes for this fiber. The heat treatment necessary after dyeing dictates the use of dyes fast to sublimation.

Blends of Arnel with rayon can be dyed conventionally.

An important contribution on the chemistry of dyes for hydrophobic fibers was presented by Schroeder and Boyd this year at the Perkin Centennial.^{31a, 31b}

Finishing

Static. One of the properties possessed by many of the newer synthetic fibers is their ability to build up static due to their hydrophobic properties. Many nondurable agents for processability are available, and their performance characteristics are good. However, for apparel and other end uses, no durable agent having all the desirable properties necessary has yet been developed. Most of the commercial products lose their antistatic properties and discolor under conditions of commercial dry cleaning or under washing with detergents or chlorine bleaches, or they tend to soil more readily. Most agents are polymeric in nature and have hydrophilic groups to "drain" the charge. Some of these agents are suitable for fibers with rough cross sections and are not useful for those having a round cross section. Progress has been made, and continued research should continue to yield more useful products.

Miscellaneous. Silicones continue to enjoy considerable use. They add desirable properties, whether used alone or with other resins on fabric of synthetic fibers and blends, involving desirable handle- or water-repellent properties.

Uses of chemicals and resins in finishing blended synthetic fabrics were discussed in a recent summary.³² Fabrics constructed of blends of Orlon or Dacron with other fibers were covered for dimensional stability, resiliency, water repellency, and bodying characteristics.

A recent summary on surface- and resin-finishing effects on nylon has been published.³³ Surface effects can be produced by phenol printing, hot-roll embossing and calendering, and by the longitudinal random wrinkle. Thermoplastic fibers can be molded as desired to many unique patterns and designs. In addition, the use of resin finishes greatly diversifies the uses to which nylon can be put.

The 66 nylon is often heat set in a jig during the scouring and the dyeing. The 6 nylon does not respond as readily to this treatment.

* Registered trade-mark of Celanese Corp. of America, New York, N. Y.

Acrylic fibers are finished with nondurable cationic agents. A durable one would be desirable. Avitex* ML softener has been found to be a useful cationic softening agent that has built-in rewetting properties.

In finishing Dynel, blushing is evident after dyeing at 205° F. The fiber is relustered by the use of dry heat not in excess of 240° F. Blends of Dynel with rayon are relustered by the heat in conjunction with the usual resin curing.

In finishing Dacron, pill-resistant treatments have been evolved.³⁴ They include brushing, shearing, heat setting, and singeing. Brushing removes loose fibers and raises others so that they can be cropped later either by shearing or singeing. The heat setting fixes the remaining fibers of Dacron in their woven position so that potential pill formation is greatly minimized.

In finishing Arnel, a heat treatment of 400° to 450° F. for 20 to 30 seconds is necessary to cause better penetration, to increase the washing fastness of dye, and to impart desirable fiber properties.

Summary

We have discussed progress in the dyeing and finishing of nylon, Orlon, Acrilan, Dynel, Verel, Creslan, Zefran, Darlan, Dacron, and Arnel. New developments have been described, and unsolved problems have been cited.

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NEW HORIZONS WITH STRETCH AND BULK YARNS

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While the title of this article appears to indicate that stretch yarns and bulk yarns are different in nature, I consider stretch yarns to be merely bulk yarns with extended horizons. All bulk yarns can be classified either as "torque" or "no-torque." Torque yarns, when permitted to hang free, rotate clockwise or counterclockwise as they unravel. No-torque yarns exhibit little or none of this tendency.

A second method of classification divides the bulk yarns into "bulked" and "bulky," according to whether the bulkiness is innate or induced.

The British textile industry has recently defined bulked yarns as follows: "Those yarns which have been treated physically or chemically so as to have a noticeably greater apparent volume or bulk, sufficiently stable to withstand yarn processing tensions and the normal forces exerted on garments during wear."¹

Bulky yarns are those in which the apparent mass of the fibers is much greater than it is in reality. This group includes yarns made with fibers that are hollow, extremely irregular in cross section, or very resilient. The physical characteristics of the latter two types prevent close packing of fibers in spinning and weaving, thus increasing the covering power of the resulting fabric.

At present, none of the bulky yarns can be regarded as stretch yarns. In addition, all of them are no-torque yarns.

While this paper is concerned primarily with polyamide and polyester yarns, the processes described in many cases were developed originally for viscose and acetate yarns.

The history of bulk and stretch yarns is entwined with that of the search for a satisfactory method of producing synthetic fibers capable of replacing wool.

While the textile industry was still absorbing artificial silk, now called rayon, various groups of investigators were seeking ways to manufacture an artificial wool. It was this work that eventually developed the bulk yarns of today. In the late 1920s, bulky yarns were made from hollow fibers prepared by the incorporation of air into the liquid from which the yarns were spun. Some bulky yarns were made from unstretched viscose fibers that, while of low tensile strength, possessed the resiliency and irregular cross section necessary for the production of wool-like yarns.

In the mid-1930s, a series of patents, in particular those granted to various inventors working for the Heberlein Patent Corporation, New York, N. Y., and the Celanese Corporation, New York, N. Y., claimed that wool-like yarns could be made from rayon threads by twisting such yarns to at least 4 times the conventional number of turns per inch, setting the twisted yarn in wet steam, drying it, and then back-twisting it to the starting point. It

was claimed that this effect could be secured equally well by the use of a false-twist spindle with heated yarns, particularly thermoplastic yarns such as cellulose acetate. The same group of patents demonstrated that yarn so treated could be reeled into skeins and steamed at a pressure of 3 atmospheres to secure an increased circular crimp or, as we are terming it, bulk.

As late as 1947, a British patent was issued to Heberlein that covered a process for making wool-like fibers from cellulosic fibers by treatment with a swelling agent, then giving the yarn a temporary high twist in a false-twist spindle, and then stopping the swelling action immediately.

It is quite possible to secure satisfactory bulk with viscose and acetate yarns. The bulk of viscose yarns can be preserved by a reaction involving formaldehyde, according to one patent (U. S. 2,304,089 Dec. 8, 1942, George Heberlein).

The bulking effect is retained in thermoplastic yarns such as secondary cellulose acetate if the strains imposed do not exceed the elastic limit of the base yarn. With this knowledge it appears possible to use bulk cellulosic continuous-filament yarns in clothing and industrial fabrics.

All of these patents, while they concern cellulosic yarns, describe processes that, when applied with suitable changes in temperature to polyamide or polyester yarns, produced bulked torque yarns that yielded a surprising dividend; that is, "stretch."

Stretch yarns are continuous-filament bulked yarns that have been deformed physically and set to develop not only a high degree of potential stretch, but a usefully rapid recovery. Both torque and no-torque yarns can be found among the present stretch yarns.

Torque stretch yarns are continuous-filament yarns that have been subjected to suitable combinations of twisting, heat setting, and chemical action. In the Helanca* process this effect is accomplished by twisting the yarn to a high number of turns per inch by the use of conventional twisting machines. The highly twisted yarn is then steamed in an autoclave at a steam pressure of 15 pounds or higher. The yarn is then dried and back-twisted through the point of origin. Similar yarn is produced in a continuous process when heated yarn is passed through a false-twist spindle.

In the special case of monofilament yarns, heat setting can precede twisting. There is no back-twisting in this case.

The elasticity of the torque-type stretch yarns is quite similar to that of a group of untwisted coiled springs tending to return to the coiled state. The springs are fully extended by a load no greater than 0.4 gm./denier. If a single strand is thus extended, 90 per cent recovery can occur in less than 1 minute after removal of the load.

Because the torque of such yarns is transferred to the fabric, these yarns were originally plied, one strand that had been spun clockwise being used with another that had been spun counterclockwise.

When a plied multifilament yarn is extended and the tension is then released, a recovery as high as 75 per cent can be expected within 2 minutes.

* Registered trade-mark of the Heberlein Patent Corp., New York, N. Y.

Full recovery can be secured by steaming the yarn or immersing it in boiling water. The partial recovery appears to be due, in the main, to interference and interlocking between coils of adjoining filaments. Steaming or boiling in water introduces enough lubrication and release of strain to permit additional contraction.

The analogy of springs, used above, can be applied most easily to the twisted monofilaments, each of which is similar to a highly twisted torsional spring. When two such monofilaments of opposite torque are held together, there is no opportunity for them to untwist and return to a state of lower torsion. Therefore little or no contraction occurs once the structure is completed. However, when several filaments are free to turn in the same direction, untwisting can occur when the extending force is removed, and a fabric made from them will be elastic.

The torque monofilament yarns are used in fabric construction in alternating groups or bands of at least two strands, each composed of one clockwise and one counterclockwise torque yarn. Fabrics also can be constructed according to this principle with multifilament torque stretch yarns. Such yarns are not true coil springs, however. A true coil-spring yarn would possess no torque, and none of this type has been marketed as yet.

No-torque stretch yarns include those that have been deformed by being passed, at elevated temperatures, through a stuffing box, over a sharp edge, between gears, or through a rapidly reversing false-twist spindle, and those that are deformed or crimped by being knitted into a fabric, set, and allowed to unravel. A simplification of this process involves feeding the yarn continuously into a rotating circular knitting head with heated needles, the crimped yarn being extracted continuously when it has nearly completed the circuit.

The no-torque yarns produced by the use of stuffing boxes, gears, or knitting can be represented as a series of cantilevers attached one to the other at the apex of each fold or curve. Because the motion of such series is essentially linear in extension or contraction, little or no interference is experienced between adjoining strands. Unfortunately, the extension that can be built into the yarn by this wave or fold technique seldom exceeds 85 per cent of the contracted length. By comparison, torque yarns show as much as 300 per cent extension of the contracted length. It is this difference in potential extension that differentiates the yarns that I consider to be true stretch yarns from the remainder of the bulk yarns.

There is, however, a group of no-torque yarns that shows adequate stretch. This group includes those produced by pulling plastic filaments over a sharp edge and those produced by introducing alternating lengths of opposite torque along the yarn. These yarns, although they appear to have no torque, are torque yarns in that they are coiled or twisted locally. It is this multidirectional coiling of the yarn that produces a collapsed bulk yarn that can be extended at least 200 per cent. Such yarns, when in their contracted state, are easily fitted into the British description of bulked yarns quoted above.

In order to complete the category of bulked yarns, we must include those

multifilament yarns, typified by Taslan,* in which loops have been formed by agitating the relaxed yarn in a high-velocity air jet. Staple-fiber yarns in this group include those that are formed by twisting conventional textile fibers together with fibers of high potential shrinkage and then activating the shrinkage, as discussed elsewhere in these pages by Soday.

At this point, having already dealt with history, methods, properties, and possible changes in manufacturing, I shall describe my idea of the future of these yarns.

The hollow-filament bulky fibers, primarily those of viscose, now limited in use because of their low tensile strength, may return in a new guise if and when a method of introducing gas into melt-spun and drawn fibers is developed. However, I believe that competition from fine, solid, resilient, or crimped fibers will limit the economic future of such hollow fibers.

The synthetic fibers that have high potential shrinkage already have demonstrated their usefulness in bulked yarns when, as cut staple, they are spun together into yarns with other synthetic or natural fibers. In the area of continuous-filament yarns, similar fibers have resulted in the development of a whole new group of decorative fabrics, the so-called "3D" materials. In addition, when used as components of plied yarns, these fibers have been used to develop new textures in carpet faces, knitted outerwear, and woven textiles.

Obviously, a whole spectrum of continuous-filament torque-type bulk yarns can be produced by reducing the number of turns used to deform the yarn. For this reason alone, competition between twisting and crimping methods should be more intense in the area of bulk yarns than in that of the stretch yarns. The fact that a bulking effect can be produced in equipment usually found in textile plants, particularly those that twist filament yarns, seems to have been overlooked in the immediate past. A reduction in the range of stretch can be produced by treating stretch yarns in boiling water or by means of pressure dyeing. If desired, such bulking also can be accomplished by dry heat. It appears logical to assume that stretch torque yarns can be produced by introducing a false spindle or sharp edge between a spinneret or yarn-drafting unit and the ultimate collecting package, whether it be a spool, pirn, bobbin, or other textile support.

The possibilities of inserting the air jet or the crimper-box device into synthetic-filament producing systems are evident. Either of these arrangements should result in less handling and lower processing costs for the no-torque bulk yarns. Decisions as to when and how this will be done must, of course, remain with the manufacturers of synthetic yarn.

The future of the bulked yarns of the Taslan type are discussed by Richardson, Stanley, and Heckert elsewhere in these pages; further elaboration is consequently unnecessary at this point.

The high-stretch yarns are now used widely in men's socks, are becoming important in women's hosiery, and are also being used in all other fabrics of knitted construction. The fact that torque stretch yarns need not be

* Registered trade-mark of E. I. du Pont de Nemours and Company, Inc., Wilmington, Del.

plied, but can be used in opposite torque in alternate picks, ends, feeds, or courses, has permitted the development of stretch fabrics much lighter in weight than has been possible previously. The fact that stretch fabrics conform to curved shapes, such as furniture, makes them useful in upholstery covers. The same property has resulted in exciting sweaters, neat-fitting undergarments, and comfortable belts, suspenders, girdles, and similar elastic accessories. The recent announcement of a stretch bathing-suit fabric opens a still wider horizon for the coming season.

The intermediate group of synthetic torque and no-torque bulk yarns with limited stretch is, in my opinion, the one most likely to compete successfully in fabrics designed for the retention of tailored shape. These yarns have a resilience comparable to those of wool, a moisture-holding capacity equal to those of cotton, a strength approaching that of untreated yarns of the same composition, and the built-in ability to return to their original shape after having been stretched. The technical difficulties involved in weaving these yarns are being solved rapidly. These yarns may be used either alone or in combination with other synthetic and natural fibers.

I can easily imagine, in these yarns, the Cashlon flannel slacks and the Newlon shirt of the hero of Shepherd Mead's *The Big Ball of Wax*.² However, we shall not be forced to wait a generation to see them. In fact, we should have such shape-retaining fabrics within the next three years.

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WHAT THE TEXTILE CONSUMER EXPECTS FROM SCIENCE

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I am, of course, honored to have been asked to contribute to this monograph. At the same time, I have an overwhelming feeling of responsibility, for I seem to be the unofficial spokesman for the individuals who constitute that vast market for which all these textiles have been made. Some of the problems that I shall discuss have been created out of the textile industry's blindness to the fact that consumers are individuals, regardless of their social or financial status in the community and that, as such, they have profound individual likes and dislikes, loyalties and inconstancies. The pages of our more expensive consumer magazines and the columns of our newspapers are full of textile advertisements appealing primarily to the wealthier sections of our community. Stylists are very conscious of the tastes of the members of this group.

In accepting the responsibility of reporting on what the textile consumer expects of science, I found some preliminary field work necessary. Accordingly, within the past few months, I have questioned numerous customers—and by that, I mean the store customers. I have also queried, by letters and questionnaires, another consumer group—leaders in the field of home economics, home extension specialists, clubwomen who head important committees in the field of consumer interests, and others who are in a position, not only to express themselves, but to serve as molders of the thought and habits of the consumers of tomorrow and as educators of the housewife and the youth of our country.

Several viewpoints became apparent almost immediately.

What Is Science?

First, science, to the average member of the consuming public, is represented as a respected but somewhat mistrusted white-coated individual who is identified with the splitting of the atom, interstellar travel, the artificial planet, the new life-saving biochemical products, the superpower gasolines, the synthetic detergents, and the vast confusion created by new textiles and their names. For the purpose of clarity, I desire to limit the scope of my presentation to the textile technologist rather than to science as a whole. After all, it is the textile technologist who is on trial today. I repeat that this investigator is on trial, for there seems to be a feeling on the part of many a housewife that he has helped her household purchasing up to a certain point, and then has deserted, if not actually betrayed her. The thought is present that the textile technologist is always primarily loyal to the source of his financial security—to the selling side of the retail counter.

New and wonderful products have been developed, and they have been advertised and publicized to such an extent that consumer receptivity has been established. After this, however, the technologist has deserted the

consumer and left her to her own devices and experiences when she has to make her selection. As one prominent leader in the consumer field expresses it: "Is science involved when an expert promoter uses his knowledge of psychology to induce a consumer to want what the promoter wants him to buy?" This is more than a hint at betrayal. Not unlike this accusation is a question I almost invariably hear when I am speaking before a women's club or other consumer group. Almost always, the question is raised: "Is it not true that nylon stockings could be made to last much longer if the manufacturers wished them to do so?" As a corollary, it is not at all unusual for us to hear the statement: "Nylon is not nearly as good as it was before World War II. We feel that the manufacturers have deliberately cheapened it in order to sell more of it." Of course, these charges are ridiculous, but the fact does remain that today's nylon stockings, due to their increased sheerness since World War II, do not last as long as formerly. Whether these extremely sheer hose are forced upon the public by the manufacturers, or whether the public has specified to the manufacturer that only extreme sheers are wanted, is a highly controversial question.

Is the Sales Department Boss?

The same consumer leader has added another challenge for the textile technologists to answer on the charge of desertion: "The scientist in private employ may develop a new product useful for particular purposes, but he may have no control over the company's promotion and sales staff if they imply wrongly that the product is useful for many other purposes. Should one suggest, in the latter case, that the scientist resign his position after making a statement to the press?" The overselling of products is not peculiar to the textile industry. A certain amount of it is regarded as harmless puffery, but the fact remains that it is not uncommon for a new product to reach the market before it is really ready and before all of the quirks and idiosyncrasies of the material have been explored. Very often the sales force is responsible, and the laboratory technician or the chemist in the plant has no power over what the sales department does with or says about the product. Each mistake of this kind has a profound and long-lasting effect, not only as far as a particular fiber or finish is concerned, but as regards all new fibers and finishes. The lines of communication between consumers function night and day, and as first-hand legitimate complaints become second-, third-, fourth-, and fifth-hand reports around the bridge table or over the telephone, they become increasingly inaccurate and general in their application. Have you ever tried that dinner table or party game of whispering a message in the ear of your neighbor to your right and having that message progress person-to-person all around the table until it reaches you again through the voice of the person on your left? Any resemblance between the original message and the one you hear is purely coincidental. In this consumer communication line, sins and omissions on the part of the manufacturer or retailer are rarely minimized.

The Consumer as a Laboratory Animal

The consumer does not expect to serve indefinitely as a guinea pig in the development of new and everexpanding market applications for a new textile product, especially when she has bought the merchandise in good faith. Sometimes she has been lured into making the purchase by promises of miracles rivaling those of the old-time medicine-show operator. On the other hand, if she knows in advance that a certain fabric or finish is under experimentation and that the manufacturer would welcome her comments for and against the product as she has used and cleaned it, she would be much more open-minded. Also, she might then be more critical of her own methods of care and use. She would be the first to admit that a manufacturer must endeavor, in his own self-interest, to find as many uses as possible for his product, whether it be a fiber, a finishing compound, a dye-stuff, or some new blended fabric. However, she is becoming increasingly distrustful of this shotgun technique by which so many textile products have been directed into wrong and economically wasteful end uses. Who is blamed for this? Not the maker of the garment, the curtain, the drapery, or other textile product, but the fiber from which it was made and the store from which the goods were purchased.

Doesn't Anyone Down Here Like Me?

Now let us examine a little more carefully the consumer's charge that the textile technologist is almost exclusively on the side of the seller, and not that of the consumer, when the goods reach the retail counter.

The housewife finds it difficult to translate some of the "miracle" features she had heard ascribed to a new fiber into its performance in a fabric, let alone its performance in a dress, a suit, or a pair of slacks. The characteristics of the fiber are not necessarily the same as those of the fabric. Why does not science or, I should say, the technologist, tell her the difference? The consumer is accused of misplacing, losing, or discarding labels without reading them; but when the same label is available on a wide variety of fabrics and garments, and particularly if it appears to be the label of a soap company and not that of the textile producer, she has reason to doubt the technical accuracy of the information contained thereon. How does she know whether the proper label was put on the garment she has bought? She has a profound mistrust for labels reading, "Dry clean only" attached to the collar bands of dresses, shirts, pajamas, and other things that she has traditionally washed with success. Therefore, you cannot blame her for being confused when she picks up a label that reads "Completely washable." Is this statement completely reliable? "Partly washable" is as meaningless as "partly dead."

Science Should Guide

The consumer expects science to guide her in the purchase of textile items best suited to her own individual requirements. Admittedly, no consumer or consumer educator makes that statement as fully, or in terms equally forthright. However, such reports as the following would seem to sub-

stantiate that conclusion. A prominent leader in the Home Economics Education Branch of the Department of Health, Education, and Welfare of the Public Health Service, Bethesda, Md., says: "The consumer wants science to make available to her more information about fibers and fabrics. For example, 'Why can't we find out as consumers such things as whether permanent pleats are really permanent, and how warm Dacron is?'" From a specialist in Maine comes the question: "Whose responsibility is it to see that fiber, fabric, and finish are combined for a specific end use as dictated by consumer wants?" From the Extension Service in the state of Nebraska comes the request for "more research on comfortable clothing for hot, humid weather"

Science would have a difficult time answering these and many similar questions that have come to our attention and that of others engaged in the evaluation of textiles for consumer use. The consumer is asking for guidance because she herself does not know exactly what her wants and requirements are. How, then, can science offer help and guidance? I think science can do so only through a clear, concise, and accurate educational program directed not only toward the homemaker, but also toward the needs of the home economics teacher and, particularly, to the extension specialists operating through our land-grant colleges in almost every state in the country. A modification of this program could well be directed toward the training departments in retail establishments and to their salespeople. Such promotional materials are available now, I know, but too often they are couched in ambiguous double talk, which carefully conceals all the weaknesses and problems possessed by the textile material. Such promotional efforts are based on half truths.

In expecting science and the technologist to supply her with information as to her own particular wants and needs, as an individual the consumer can be of little aid. However, her habits, her patterns of purchase, and her consumer behavior aid the social scientist in developing certain general laws or formulas that enable manufacturers to design goods with more customer appeal and to guide distributors into better satisfying the mass demands of their local clienteles. It is not this socioscientific approach, however, to which I refer in this paper. I am dealing more with the pure scientist, the chemist, the physicist, and the textile engineer, from whose brains and skills have come such a wide variety of textile products. In broad, general terms, we might say that we should expect the social scientist to tell something of the "whys" and "whens" of consumer purchasing; the consumer, however, wants the "whats" and "hows" to be answered by the natural scientist. The consumer is nonvocal as to her own needs and wants in almost any type of textile commodity. If she cannot express herself as to what these requirements are, then how can science or technology offer her guidance?

What Are Some of the Information Needs?

Through their contact with consumers, usually the rural or small-town housewife, consumer leaders, including extension specialists, have arrived

at specific cases and examples where information would be highly desirable. To a remarkable extent, the observations of these learned and experienced women correspond to those of store laboratory technicians whose contact with the public comes through lectures and meetings with consumer groups in the store's local big-city market and through the study of consumer complaints in the form of returned merchandise. Let us look at some of the specific questions asked of us by these consumer leaders from some of our home economics departments in land-grant colleges.

(1) *With regard to color*: guidance as to source of fabrics more resistant to sun-fading; information on the bleaching of synthetic fibers; what to do about fabrics that have yellowed in washing; and improved wash fastness of color.

(2) *With regard to durability*: general condemnation of today's sewing thread; loss of crisp, stiff finish after one or two washings; poor balance in fiber blend or of yarn geometry, producing a fabric that splits and breaks in one direction; loss of permanent pleats; and minimum-care fabrics that are not truly washable without ironing.

(3) *Conditions of care*: more information about removal of oil and grease stains from "modern" fabrics the spot- and stain-resistance claims for which apply only to water sources; better information on washing *versus* dry cleaning and on bleaching; how best to store some of these new materials and blends; and whether a textile product can be dried safely in a household dryer.

(4) *With regard to appearance*: which fibers and fabrics are most prone to pilling; how best to produce nonpuckering seams with the synthetic fiber garments; the elimination of static so that garments will hang better and also resist the accumulation of dust; and how to find sweaters and T shirts that will not stretch in width or distort around the neckline.

Admittedly, to fulfill all these demands for specific information would require far more than a label on a product. Producers and distributors of textiles have the firm belief that consumers do not read the labels presently furnished, but how many of these labels embody concise technical facts that can guide the consumer in her use and handling, as well as wearing, of a given article?

It can be argued, too, that consumers have no intention of going to school again to learn about the new textiles. Nevertheless, would it not be possible for the textile industry to have printed a concise, accurate textile guide giving the properties and best use applications of all fibers? Then, on the reverse side of the label attached to the garment, there might be coded simply the page reference to strong points of the fabric as well as cautions and hints for its best care in use. Here, too, could appear references to special bleaching problems, to the removal of grease and other stains, to ironing conditions, to drying, and to dimensional stability insofar as these fibers in the garment customarily react to those conditions. Thus, it would not be necessary for the consumer to test every fabric for its specific characteristics.

A Mathematical Concept of Value

It is reasonable to suppose that all of the technologists in the laboratories of retail distributors have formulated some kind of equation whereby the

textile products offered by two or more manufacturers may be evaluated in terms of consumer acceptance and consumer usefulness as envisaged by the laboratory. To a certain extent this is guesswork. However, from knowledge of consumer habits demonstrated across the retail counter and from dealing with consumers in satisfying adjustment claims (when consumers usually are truly gifted with words) there evolve certain important criteria that can be treated mathematically.

In our own case, we evaluate each of the competitive products in terms of value by an equation in which $V = (W + N + C)/D$. In this equation, V stands for value; W = consumer wants; N = consumer needs; C = care required; and D = the retail dollar cost. Under wants (W) might appear such ratings as the desired color, accuracy of size, washability characteristics, and sunfastness. Under needs (N) could be listed strength requirements, specific construction features, and other colorfastness criteria tied in with a particular end-use product. Under care (C), would be included qualities such as degree of washability, frequency of ironing required, ability to withstand spotting and staining, and permanency of finish. Thus, if two or more items are compared, we can rate them in the order in which they satisfy these wants, needs, and requirements for special care. Under this system, the higher the figure for value (V), the better the article as compared with its rivals.

On occasion, we have urged consumers to set up a somewhat similar kind of mental comparison equation in judging, for example, the degree of satisfaction or value to be expected of two navy-blue dresses, or of two suits or topcoats. In this case, we have urged the consumer to consider how each item fits in with her present wardrobe, and the extent to which other accessories might be required to make the ensemble more suitable. This is particularly true in women's wear, but the male consumer, likewise, could benefit from this sort of appraisal. One advantage of numerical classification is that it makes the consumer conscious of differences between what she would like and what she actually needs. It puts additional emphasis upon serviceability, bringing it closer to style and fashion in the mind of the consumer.

It's the Use that Counts

Again and again, consumer leaders have urged that science take an increased interest in field-test observations on textile products. Admittedly, this kind of testing is expensive. Worse than that, it is slow. Some is being done, as is well known, by many of the textile-producing firms, but whether these tests are sufficiently random in their test subjects is an open question. Here, the extension specialist and the land-grant college can be of tremendous aid to the producer of fiber or fabric, as some of our manufacturers have already learned. Consumer preference studies, wear tests at school, or play, or at work, and other types of direct consumer reaction should benefit the manufacturer directly and the consumer eventually. Some of our textile experts who have answered my questions ask pleadingly, "How can we help scientific laboratories and manufacturers by performing

wear tests on garments?" Another question asked was: "Would textile scientists be interested in having some sort of setup with a clearing house for consumer experiences and reactions?" A challenging question asked was: "Do manufacturers know what consumers want to read on their labels?" An important consideration that industry might give to this sort of cooperation involves the increased encouragement it would give to young men and women with talent for research to consider the field of textiles as a life work. It would surely give increased confidence to the textile teacher and probably help the field of education to recruit the new young blood for which it now cries so desperately. If the teaching and practice of textile economics seem practical and worthwhile to industry and to the consumer, then both teacher and pupil will take increased pride in textile education as useful and meaningful.

Do Manufacturers Really Know Consumer Opinion?

From time to time, department store salespeople and customers alike have wondered as to the identity of the consumer advisor to the average textile producer. Is it the stylishly dressed, smart young woman who visits the stores and distributes all of the rather biased sales material on her company's products? Is it the person who laughs off or disregards any question directed at some well-known flaw in the product that consumer use has revealed? Is it the laboratory scientist who is several steps away from contact with the consuming public, and who may be overly engrossed with the properties of fibers, and forgetting that the consumer buys fabrics and wearing apparel, and not textile fibers? Is it the sales department, fortified with modern psychology and knowledge of consumer whims and fancies, who supplies, in pseudoscientific terms, the "essential" facts about the performance of a textile in service? This advisor may, in effect, be all of these persons, with the result that vocabularies are different, claims are contradictory, facts are loosely worded, and that all that is accomplished is to create more confusion for the consumer. Science and technology have a story to tell. We must find our medium of communication. We must give more than casual regard to quality and durability, with less emphasis on price. The American textile industry has legitimate complaints about retailers. Too many of them tend to give only lip service to quality, as witness their extensive programs for the development of minimum or threshold consumer-use standards for textile products. Then, after having demanded the production of marginal goods in this country, some turn away from their domestic suppliers and import large quantities of low-priced basic goods from low-cost producers abroad.

All I have said might be summed up in one sentence: the consumer expects the scientist to be as interested in following the use of a new textile product in normal household service as he is in determining in the laboratory its elongation, its breaking strength, its modulus of elasticity, its colorfastness, its electrical conductivity, and all the rest of its properties. The housewife expects the textile technologist to exhibit as much interest in and influence over her proper care and use of the product as in the way it is to be promoted

over the retail counter. She demands that science listen to her reactions to these new products so as better to develop and devise new fibers, finishes, and dyestuffs. She expects the use of a common vocabulary so that she will not feel that she is being patronized as one not quite bright enough to understand the facts when she listens to the technologist or to the retail salesperson. She expects that every textile product reaching the market and coming into her home will have built into it as much real serviceability and quality as can be had for the price she is willing to pay. When she complains that an item is unsatisfactory, she expects the store buyer, the garment manufacturer, and the textile producer to regard this as a warning of a potential epidemic of trouble rather than merely as the isolated report of one disgruntled or disappointed person.

The consumer expects facts. She expects statements to be accurate and truthful. In the absence of a label she realizes she is buying blindly, and that, given the choice between (1) a product that is labeled or branded, and about which certain facts are disclosed, and (2) a blind purchase, she would be foolish, indeed, if she were to choose the merchandise about which she knew nothing except that it was cheaper. She expects science, at every level of production and distribution, to be willing to consult with her and her guides, the home economics experts, in developing higher standards for some of the textile merchandise she wishes to buy.

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